MILITARY WORKS HANDBOOK

FIFTH EDITION

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PREFACE TO FIFTH EDITION.

THE first edition of this book was prepared in 1877 by Mr. R. T. Tyndall, M.I.C.E., Superintending Engineer, third circle, Military Works, for use in the Meerut, Agra, Bareilly and Morar Divisions of Military Works.

The value of the book soon became widely recognised and it came into general use, not only in the Military Works Department, but in the whole of the Public Works Department.

The second edition was prepared in 1885 under the direction of Colonel J. J. McLeod Innes, R.E., Inspector-General of Military Works : the work of revision was supervised by Colonel Ward, R.E., assisted by Captain Turner, R.E., and Lieutenant Tanner, R.E.

On a reprint of the second edition becoming exhausted, a third edition was prepared in 1900 under the direction of Major-General S. C. Turner, Director-General of Military Works.

The fourth edition was issued in 1908 having been prepared under the direction of Major-General H. W. Duperier, Director-General of Military Works.

Owing to the great demand for this book a fifth edition has become necessary sooner than was anticipated.

The book has now been entirely rearranged and largely re-written by Captain W. H. Evans, R.E. : important additions and changes have been made in the sections dealing with estimating and calculations, while specifications for reinforced concrete work have been included.

It should be noted that this book is not intended to supersede standard works on the subjects dealt with, but is merely a Handbook for use generally in the preparation of estimates.

G. WILLIAMS, *Major-General,*
Director-General of Military Works.

(This book includes all corrections up to, and inclusive of, List No. 3, dated 28th December 1917.)

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Military Works Handbook

SECTION I.

Estimates.

1. Estimates are of three kinds :—Rough or Approximate, Plinth Area and Detailed. General.

2. Rough estimates or approximate statements of cost are usually required only in the case of large schemes to enable Government or senior officers to decide whether the scheme is worth further investigation. Thus in the case of a proposal to establish a factory, before sanctioning any particular sum for the buildings, etc., Government require to have the whole cost of the proposed scheme before them, including land, water-supply, buildings, machinery, establishment for working, etc., so that they may decide generally whether the project should be gone on with. Such schemes are laid before Government by the department or other senior officers concerned, and the preliminary rough estimates are called for through the department from the Assistant Commanding Royal Engineer of the District. Rough Estimates.

3. It is to be understood, therefore, that a rough estimate or approximate statement is not submitted for sanction to a definite sum. It must generally in the case of buildings be based on plinth areas, but these need not be accurately taken out. In the case of lines for troops, the areas, as given in Army Regulations, India, Volume XII, Appendix V, will be sufficiently near. In the case of roads, rates per mile, or rough calculations of the amount of excavation, walling, etc., will generally suffice.

4. When Government have decided that the scheme is to be proceeded with, plinth area estimates, in the case of buildings, and abstract estimates, in the case of roads, water-supplies, etc., are called for through the Director-General of Military Works. These estimates are forwarded to Government for sanction to a definite sum and must therefore be carefully taken out. Thus in a plinth area estimate for buildings, it must be decided of what materials the different parts are to be constructed, how thick the walls are to be, etc., etc. Plinth Area Estimates.

5. The notes on the plinth area estimate form require that the estimate shall contain a report, a general specification, an explanation as to how the rates have been arrived at, and the details

Plinth Area Estimates—(*contd.*).

giving explanation of the buildings required, skeleton plans, plinth areas, rates and amounts.

Report.

6. The report should briefly detail the correspondence which has led up to the preparation of the estimate, and should explain how it is proposed to provide the necessary accommodation, and, if any alternatives have been considered, why a particular scheme is recommended: the specification should state of what kind of materials each part of each kind of building is to be constructed. The detail of rates should explain how the plinth area rates have been arrived at. In the detail sheets the buildings will be dealt with in the same order as in Army Regulations, India, Volume XII, Appendix V. In column 3 it should be explained clearly how many men, horses, etc., have to be provided for, and in what buildings they are to be accommodated. If any existing buildings are available they should be detailed and outline dimensioned plans given of them as well as of any new buildings proposed.

7. In the case of abstract estimates for water-supplies, etc., the same general principles should be followed.

Detailed Estimates.

8. After administrative sanction has been given to a plinth area estimate, technical sanction is required to the detailed estimates. A detailed estimate may also have to be submitted for works or repairs for which no plinth area estimate has been sanctioned.

9. A detailed estimate will consist of a list of references, report, general specification, detailed specification, calculations, details of measurements, abstract of cost and drawings. Rough pencil drawings accompanied by a specification will usually be first prepared and submitted to the sanctioning authority for approval.

10. The pages of the estimate should be numbered consecutively. After the report an index to the drawings accompanying the estimate should be given and, in the case of large estimates, an index to the various portions is also necessary.

11. On the first page will be given a list of references with a précis of the correspondence calling for the work. The references should be arranged in chronological order.

Report.

12. The report should be arranged under the following marginal headings :—

(*a*) History of case. The circumstances leading up to the preparation of the estimate and the necessity for the work are to be briefly stated. If the estimate forms part of a sanctioned plinth area estimate, it is sufficient to quote the number of the item in the plinth area estimate and the amount there entered for the work.

(*b*) Accommodation authorised. The references to the item in Army Regulations, India, XII, Appendix V, is to be

quoted and the accommodation there authorised given in detail. Report—(contd.).

(c) Accommodation existing. This will be given in detail and, if necessary, the state of repair, etc., mentioned.

(d) Accommodation proposed. The accommodation it is proposed to give will here be dealt with; also the manner in which it is proposed to utilize any existing accommodation. Any alternatives should be discussed.

(e) Design proposed. Any reasons for departing from the standard plans should be given. The methods of construction and material proposed should be discussed.

(f) Site. The reference approving of the site selected by the Standing Barrack Committee should be quoted; if no site has been selected, it should be stated where it is proposed to locate the building and when the Committee will be convened.

(g) Time. The time the work will take to complete should be given in months: as the period here mentioned will usually be entered in a contract, this point should be carefully considered.

(h) Cost. The cost of the work, the plinth area of the building and the plinth area rate will be given. Any considerable difference between the amount of the estimate and the amount entered in the plinth area estimate should be explained: where no plinth area estimate exists, the rate should be compared with that of buildings recently constructed in the same station and any large difference explained.

13. The general specification will state briefly of what kind of materials each part of the building is to be constructed and should be arranged under the following marginal headings:— General Specification.

(a) Clearing and levelling site.

(b) Foundations. State the nature of the soil, the depth to good soil, the depth and width of the foundations and the material to be used.

(c) Plinths. Give the height of the plinth above ground level and the materials employed in its construction; also the nature, width and depth of any plinth protection to be provided. Damp proof or white-ant proof course, if any, to be described.

(d) Superstructure. Detail the materials to be used for the walls and how the surfaces are to be finished off.

(e) Roofs. Describe nature of roof and materials to be used.

General Specification—(*contd.*).

(*f*) Ceilings. State materials to be used and whether horizontal or sloping.

(*g*) Floors. Describe generally.

(*h*) Joinery. Mention wood to be used, and whether panelled, battened, etc.

(*i*) Fittings, such as punkahs, armracks, sinks, etc.

(*j*) Water-supply.

(*k*) Roads.

(*l*) Drains.

(*m*) Miscellaneous. Any items such as dressing site on completion, fencing, etc., that cannot well be included under the previous headings should be dealt with here.

Detailed Specification.

14. Where duly approved District Specifications exist, a reference to them for each item of the work will be sufficient, but, in the case of any work of a special nature or for which no specifications have been embodied in the District Specifications, a detailed specification must be given.

Calculations.

15. The calculations should be as concise as possible consistent with giving all that is really necessary. For all timber and steel beams and trusses supporting either roofs or floors, and any other items such as strength of retaining walls, etc., calculations should accompany every project.

Details of Measurements.

16. The headings given under the general specification are to be followed. Where different forms of floors or roofs are used in different parts of the building, the main heading should be further subdivided thus (*i*) main roof, (*ii*) verandah roof, etc. Quantities should not usually be taken to decimal places except in the case of woodwork, ironwork and moulded reinforced concrete. The scantling of timber, etc., is to be given in inches and not in fractions of a foot.

Abstract of Cost.

17. The arrangement of the abstract will follow that adopted for the detail of measurements. After the headings roofs, floor and ceilings, will be given the total area of the roof, floor or ceiling and the average through rate per square foot. The estimates having been totalled up, contingencies at 5 per cent. will be added. If it is considered that any special work establishment will be required to supervise the work, due allowance should be made, but the amount should not usually exceed two per cent. of the estimate. At the end of the abstract the probable amount due to the contractor's percentage above schedule rates will be added if necessary: a full explanation of the reasons for any such entry being given. In the last column of the abstract a reference will be made against each item to the corresponding item in the District Schedule of Rates: in cases where no rate has been fixed for any particular work, an explanation should be given of how the rate or lump

sum has been arrived at. Lump sum estimates for large amounts are to be avoided. The abstract will be signed by the Officer who actually prepared the estimate and by the clerks who checked and copied it: adequate space should be left for the signatures of the approving officers. Abstract of Cost— (contd.).

18. The North point is always to be given on all plans, also the direction of the prevailing wind. The direction in which doors and windows open should be indicated, and the position of the clerestory windows by a small cross and the letters C. S. W. The following scales should usually be used: plans and elevations 8 feet= 1 inch: sections 4 feet=1 inch: details 1 or 2 feet=1 inch. At least one scale should be drawn of suitable length on each plan. All drawings are to be fully dimensioned in feet and inches. Outside dimensions should be shown conspicuously and not left to be found by the addition of subsidiary dimensions. All sheets of drawings accompanying an estimate should be on tracing cloth of the same dimensions, folded neatly into foolscap size: tracings should not be folded until the requisite number of ferrotype copies have been taken. Adequate space should be left on the drawings for the signatures of the approving authorities: each plan will be signed in the first instance by the officer who has actually prepared the estimate. Drawings.

SECTION II.

General Specifications.

FOUNDATIONS.

Foundations.

1. Foundation trenches should always, where possible, be taken down to, and a few inches into, good sound soil. Before an estimate for an important building is prepared, trial pits should usually be dug at each of the four corners of the proposed building in order to ascertain the nature of the soil.

2. Wherever practicable it is advisable to take out the trenches for the main walls at the same level throughout. In a long building, such as a barrack, on sloping ground steps should be given in the foundations.

Foundations in bad soil

3. Where great depths of bad soil are met with, such as black cotton soil, it may be necessary to resort to piles, which may be of wood, steel or reinforced concrete. Where the depth of the bad soil is not excessive, the foundations may consist of beams or concrete arches on concrete pillars, the pillars being taken down into good soil. In some cases the structure may be built on a raft of concrete, reinforced with a grillage of R. S. beams.

4. Foundation trenches will usually be filled in with lime concrete: where the depth of the concrete exceeds 18 inches, it is more economical to use rubble lime concrete. For buildings of an inferior nature stone in mud or rammed moorum may be used. The plinth masonry should usually commence 6 inches below ground level in the case of outer walls: for inner walls the foundation should be taken up to ground level.

Piles.

5. Piles should usually be driven until they are able to bear 2,000 to 3,000 pounds per square inch with only a very small movement. The working load will then be from 200 to 1,000 pounds per square inch depending on whether the pile is resting on soft soil or has its point resting on hard soil.

PLINTHS.

Plinths.

1. Plinths in the plains should be not less than 18 inches high for hospitals, 15 inches for main buildings and dwelling houses and 6 inches for unimportant buildings which are not inhabited. In some situations higher plinths may be required. On uneven ground the height of plinth adopted is the minimum height.

2. For all important buildings the plinth should be of burnt brick or stone in lime mortar: in other cases mud mortar may be

used. The whole of the exterior face of the plinth should be lime pointed. Plinths—(contd.).

3. If an offset between the superstructure and the plinth is considered necessary, it should be given level with the lower surface of the concrete for the floor.

4. If the height of the plinth exceeds 6 inches, steps should be given in suitable positions : the rise of any steps should be between $5\frac{1}{2}$ and 7 inches and the tread should be between 9 and 13 inches, $5\frac{1}{2}$ by 13 being adopted for the fronts of residential buildings.

5. In black cotton soil it is advisable to remove the soil within the plinth of the building to a depth of 2 to 3 feet and to replace the soil so removed with good soil of a sandy nature. If this is not done the black cotton soil is likely to absorb moisture, expand and ruin the floor.

6. In damp sites, or as a protection against white-ants where pukka floors are given, it is advisable to provide a damp proof course at plinth level : this may consist of slate or impermeable stone in cement, asphalt (except in the plains where it is too soft), fine cement concrete or cement plaster 1 : 2. It should not be less than $\frac{1}{2}$ inch thick. It should be laid at floor level, and closely jointed to the floor.

7. Where roof gutters are not provided, plinth protection is desirable except in dry climates. In the case of more important buildings this may be of a well sloped layer of concrete or rammed stone for a width of 5 feet : for inferior buildings the plinth protection may consist of rammed moorum to a width of 3 feet. The plinth protection should not be less than 3 inches thick and it is usually advisable to provide an edging of brick or stone along the outer edge to prevent the concrete, etc., breaking away. If exposed to drippings from the roof, lime concrete will not stand well. Plinth protection.

Superstructure.

1. For outer walls burnt bricks set in mud mortar and lime pointed will generally be used. In the case of stone masonry, unless the stones have a level bed and the mud mortar is good, the masonry should be in lime. For inferior buildings or in dry climates sundried bricks mud plastered may be used. Where exposed, such walls may be faced with burnt bricks, but this work requires to be done with great care to secure a good bond and avoid unequal settlement ; with heavy flat roofs the main roof beams must be supported on pillars of burnt bricks. Outer walls.

2. In double storied buildings the lower storey will generally be in lime mortar.

Interior walls. 3. For interior walls either burnt bricks of 2nd or 3rd class or sundried bricks in mud mortar should be used.

Arches. 4. Care should be taken that the abutments of all arches are wide enough ; where sufficient width cannot be given, it may often do to build the abutment in lime or cement mortar, or in certain cases, as over doors at the corners of buildings, a tie rod may be given. The abutments of all important arches should be in lime mortar. Lime mortar should be used for all door and window openings for an average depth of 9 inches, except when steel or reinforced concrete chowkats are used. Fire places should be built in brick, not in stone masonry.

Thickness of walls. 5. The thickness of main walls of important buildings should generally not be less than 18 inches. Where they are entirely protected by verandahs, or in cool climates, main walls may be 13½ inches thick. Partition walls and the unexposed walls of verandah rooms may be 13½ or 9 inches thick.

Hooped brickwork. 6. Small partitions may be made of hooped brickwork 3 or 4½ inches thick. They should be in cement mortar if exposed. If lime mortar is used, the hoop iron should be not less than $\frac{1}{16}$ inch thick. Partitions have also been successfully made of 3 inches of lime or mud plaster on wire netting.

Hollow walls. 7. Hollow walls should generally be used for magazines : they may also with advantage be used for any walls exposed to much damp or to the direct rays of the sun.

Plastering walls. 8. Interior walls of living rooms should usually be lime plastered, if of burnt brick, and mud plastered if of sundried brick. Interior walls of stores, etc., if of burnt brick, need not be plastered.

9. Exterior walls should not be lime plastered unless the bricks are of a very inferior quality.

10. Walls for a height of 4 or 5 feet round bathing places, for 2 to 3 feet round sinks, and dwarf walls in bath rooms should be cement plastered 1 : 3.

11. In some localities it may be economical to build walls of reinforced concrete, or of moulded hollow cement concrete blocks. In others lime concrete walls have proved economical and for inferior buildings pisé and mud concrete is occasionally used : for descriptions of the latter see Specifications, Rates and Notes on Work by Captain E. L. Marryat, R.E.

ROOFS.

Tiled roofs. 1. Tiles are of various patterns, the principal forms used in India being Mangalore, Allahabad and Country, all of which may be laid single or double. Mangalore tiles are moulded in a screw press and are more satisfactory than the hand moulded Allahabad

pattern: they are laid on battens at $12\frac{1}{2}$ inch intervals, but the spacing differs slightly with the various patterns manufactured. Allahabad tiles are laid on battens at 1 foot intervals. Country tiles should only be used if the quality is very good, and even then roofs of this class are expensive to maintain. They should be prohibited in localities where Mangalore or Allahabad tiles are obtainable at reasonable cost. Tiled roofs should not be laid at a flatter slope than 1 in 2, otherwise they will leak. In exposed situations the lowest course of Mangalore tiles should be screwed down. Allahabad and country tiles should not be laid at a steeper slope than 1 in 2 or they will slip: Mangalore tiles may be laid at any slope, but the tiles require screwing down if the slope exceeds 45°. Tiled roofs—(contd.).

2. 108 Mangalore (Cawnpore pattern) tiles are usually required for every 100 square feet of roofing, but the number varies a good deal with the pattern, and in the South of India is about 130.

3 For single Allahabad tiling 105 flat tiles and 105 half rounds are required for every 100 square feet: for double tiling twice this number of flat tiles is required and in addition 105 semihexagonal tiles. At the eaves the semihexagonal and half round tiles should have closed ends: all the tiles at the eaves should be set in lime mortar.

4. For single country tiling 1,200 tiles are usually required, but here again the number depends on the pattern: care should be taken that sufficient tiles are used or the roof will leak. For double tiling a second layer only is given, hexagonal tiles not being used. They form a useful covering on G. I. sheeting but should not otherwise be used in good work. Country tiles.

5. Galvanised iron roofs may be laid in several ways. In the hills the Naini Tal pattern is usually adopted either with plain or corrugated sheets: except for æsthetic reasons corrugated iron is best laid in the ordinary way, *i.e.*, without the rolls, etc. Ordinarily 22 gauge sheets should be used for corrugated iron and 24 gauge for plain sheets: in factories corrosive fumes are liable to destroy galvanised iron quickly and it is best to use some other form of roof, but if it is considered necessary to employ corrugated iron 20 gauge should be used. Corrugated iron roofs should not be laid at a flatter slope than 1 in 4; Naini Tal pattern roofs at a slope of 1 in 2. Purlins for 22 gauge corrugated iron sheets, even when carrying tiles, may be spaced at 5 feet intervals; with 24 gauge sheets the purlins should not be more than 4 feet apart. It is best to use as long sheets as possible and a purlin should always be placed under each end. See also page 74. Galvanised iron roofs.

6. Galvanised iron roofs should always be firmly secured to the walls, both at the eaves and at the gables: this is best done

Galvanised iron roofs—(*contd.*).

by means of a steel angle or flat placed over the corrugated iron and held down at about 4 feet intervals by means of wrought iron bolts about 15 inches long with 6 inch square plates embedded in the masonry.

Tiles laid over corrugated iron roofing.

7. In Central and Southern India Mangalore and Country tiles are often laid on corrugated iron : this form of roof has many advantages, it is cool, dust and rain proof. Mangalore tiles are laid on battens fixed to the corrugated iron by small galvanised iron bolts or secured by screws from below : an airspace is thus provided between the tiles and corrugated iron. Country tiles are laid direct on the corrugated iron and a batten is fixed at the eaves, to prevent the tiles slipping ; as an additional precaution against slip, a band course of lime mortar is often given from the ridge to the eaves at intervals. This is not necessary for slopes of 1 in 3 or less.

Terraced roofs.

8. Terrace or lime concrete roofs should be laid at a slope not flatter than 1 in 20 : the concrete should not usually be less than 6 inches thick. The terrace may be supported on tiles, flags or jack arches. This form of roof is liable to crack in places where great ranges of temperature occur and should always be inspected and attended to just before the rains break. R. S. joists should always be used for terraced roofs in preference to wooden supports, as the liability to crack is much less. The concrete is best made from broken bricks or tiles.

Reinforced concrete.

9. Reinforced concrete roofs have been used in many places with considerable success : for isolated works, however, the cost of the centering renders the roof a very expensive one. Roofs of this material require very careful supervision during construction. Expansion joints should be provided at intervals of about 5 feet : they are best made by leaving a space of about half an inch between adjacent slabs, the edges of which are turned up and the opening covered by a half round tile of concrete. The thickness of the slab should never be less than 3 inches.

At Jabalpur many outhouses have recently been roofed with reinforced cement concrete moulded slabs, $3\frac{1}{3}$ feet by 2 feet by $1\frac{1}{2}$ inches thick, coloured red on the upper surface : the slabs were laid with an overlap at a slope of 1 in 2 on concrete rafters. The roof proved economical and satisfactory but steps should always be taken to render the slabs waterproof by adding slaked lime to the concrete during manufacture.

Mud roofs.

10. Mud roofs have the advantage of being cheap, but are heavy and require a good deal of attention. They are largely used in places where the rainfall is light, such as the Punjab, but should be avoided in localities where snow occurs. The form of roof usually adopted consists of 6 inches of mud laid on tiles or corru-

Mud roofs—(contd.).

gated iron at a slope of 1 in 8 : the surface is plastered and leeped. The leeping requires renewal annually and the plaster occasionally. Supports should be R. S. joists if possible.

Woodwork in roofs.

11. Timber that is unseen, *i.e.*, above ceilings, should not be planed. In some cases battens, rafters, bressummers and pillars may all be made of reinforced concrete. Bed plates are usually of stone but may be made economically of concrete : they should not be larger than is necessary.

12. Roof timbers exposed to the action of the weather should always be painted or treated with solignum : timber in contact with walls should be treated with solignum of some similar preservative especially in localities where white-ants are prevalent : all other timbers should be oiled. Earth oiling should not usually be done till the wood has been in place for some months : if applied to unseasoned wood it is liable to induce dry rot. All steelwork should be painted.

Ceilings.

Lime plaster on wire netting.

1. Lime plaster on wire netting is about the best and cheapest all round ceiling. The netting is either secured to the underside of the rafters, which should not be more than $1\frac{1}{2}$ feet apart, or for horizontal ceilings, it may be fixed to ceiling joists similarly spaced.

Mud plaster on wire netting.

2. In dry situations, where white-ants are not prevalent, as at Quetta, mud plaster on wire netting forms a cheap and efficient ceiling.

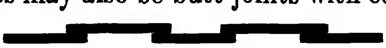
Ceiling tiles.

3. In Southern India ceiling tiles are largely used under Mangalore roof tiles. They are laid sloping, supported on the battens used for the roof tiles.

Patent ceilings.

4. Venesta, eternit or poilite sheets form excellent but rather expensive ceilings. Ceilings have also been constructed of galvanised iron sheets, the joints being covered with wooden fillets.

Boarded ceilings.

5. Boarded ceilings of teak, deodar or deal should be hung from ceiling joists at intervals of $2\frac{1}{2}$ to 3 feet. Boards should be tongued and grooved. Joints may also be butt joints with covering fillets, or lap joints laid thus . Three ply boarding, such as venesta, is to be recommended for ceilings as it does not crack or warp if the edges are supported, nor do the joints open out in the same way as in ordinary boarded ceilings ; it is however readily eaten by white-ants.

Ceiling cloths.

6. Ceiling cloths are cheaper than boarded ceilings but are very unsatisfactory in the long run. If unavoidable they should be made up in frames not exceeding 5 feet by 5 feet, the joints being covered with wooden fillets. Special whitewash is essential to prevent the fabric rotting.

Floors.

Flagged floors.

1. Good stone flagging $1\frac{1}{2}$ to 2 inches thick forms the best floor for barracks : the flags should be laid on 3 inches of lime concrete. Joints should be not less than $\frac{3}{8}$ inch, and made with P. C. mortar, except where really well dressed flags capable of giving very fine joints are available.

Terraced floors.

2. Lime concrete or terrace floors, if made with really good lime under careful supervision, are suitable for officers' and subordinates' quarters but must not be used in barracks.

Cement floors.

3. Cement concrete floors may either be laid *in situ* or flags may be moulded separately and laid when thoroughly seasoned. Work of this kind requires very careful supervision and should generally be carried out by Departmental labour : the specification for the work should be very carefully prepared and the proportions of sand and cement required to fill the voids in the aggregate should be ascertained by actual experiment. When the work is done *in situ*, the floor should be laid in strips or squares, as large expanses of cement concrete are very liable to crack. As the cost of the cement is the main item in floors of this nature, labour should never be stinted. Even the most carefully laid cement floors are apt to turn up at the edges of strips or corners of squares, owing to the upper surface contracting more rapidly than the lower surface on setting and drying out, and for this reason it is perhaps better to use moulded flags, though rather more expense is involved : the flags are laid on 3 inches of lime concrete in the same way as stone flags. Cement floors may be easily coloured by the addition of colouring matter to the top surface.

Patent floors.

4. India Patent Stone, Stonewood, Porphorylite, etc., form excellent floors but are very costly.

Brick floors.

5. Brick flat or brick on edge floors laid on 3 inches of lime concrete can be used when really hard, well made, bricks are available . in some places tiles of good quality are obtainable. Glazed bricks and tiles form good floors, though rather expensive : this class of floor may be used with advantage in certain cases, as for irrigation stands in veterinary hospitals.

Wood block floors.

6. Floors of shoeing sheds are best constructed of 6 inch cubes of hard wood, such as babool, soaked in boiling tar and laid on 3 inches to 6 inches of concrete.

Earth floors.

7. Floors of inferior buildings, outhouses, etc., may be of rammed earth, rammed moorum or Devonshire Barn.

Upper floors.

8. Upper floors may be constructed in any of the ways mentioned above, the floor being usually supported on jack arches. Boarded floors will usually be supported direct on wooden joists,

but in such cases a ceiling should be given to the rooms below. Upper floors may also be made of reinforced concrete, either by means of slabs supported on rolled steel joists or by monolithic tee beam construction, in which case the floor and beams are laid at the same time. **Upper floor—(contd.)**

9. Where sanitary considerations are of primary importance, floors should be jointless as far as possible and in such situations brick or flagged floors are unsuitable. **Jointless floors.**

10. Staircases may be supported on brick walls, on inclined beams called stringers or the steps may be cantilevered out from the wall. The rise for ordinary stairways should be between 6 and $7\frac{1}{2}$ inches and the tread between 10 and 12 inches: handrails should be $2\frac{1}{2}$ to $2\frac{3}{4}$ feet above the outer edge of the tread and at landings the height should be $2\frac{3}{4}$ feet. A landing should be given at every change of direction and at intervals on a long straight staircase. Sweepers' staircases are usually of cast iron arranged in spiral fashion round a central cast iron column. **Stairs.**

SECTION III.

Detailed Specifications.

General.

These detailed specifications are given to serve as a guide but may require modification to suit local conditions. Special specifications should therefore be prepared for each district or group of districts, and in these it should be stated clearly and exactly what work is covered by each rate in the schedule of rates, *e.g.*, if the rate for doors includes the cost of hinges, furniture, etc., the district specifications should make this clear.

Earthwork and Foundations.

Earthwork general.

1. In ordinary excavation work, such as for rifle ranges, embankments, etc., pillars, the positions of which are to be fixed by the Garrison Engineer, are to be left at sufficient intervals to permit accurate measurements to be taken on the completion of the work : such pillars are not to be demolished without the orders of the Garrison Engineer.

2. The positions and depths of borrow pits will be indicated by the Garrison Engineer, also the steps to be taken for their drainage if necessary.

Blasting.

3. Before any blasting is carried out, the orders of the Garrison Engineer are to be taken regarding the hours for firing charges, the nature of the explosives to be used and the precautions that are to be taken for the safety of the general public.

Excavation of foundations.

4. The excavation for foundation trenches is to be in exact accordance with the drawings furnished, and care must be taken that the bottoms of trenches are truly level in all directions, that any steppings ordered are strictly attended to and that the sides are kept plumb. The spoil is to be kept well clear of the edges of the trenches.

5. If rock is met with, a report is to be made at once to the Garrison Engineer and the lower surface of the trenches will be made as level and true as possible, any small inequalities being filled with concrete.

6. The bottoms of all trenches are to be well watered and rammed, care being taken that too much water is not used. Soft and defective places are to be brought to the notice of the Garrison Engineer, and the holes will be filled with concrete or treated in such a way as he may direct.

7. On the completion of the excavation, and after the work has been measured up by the subordinate in charge and the measure-

ments agreed to by the contractor, a report is to be made to the Garrison Engineer, without whose written permission no building work in foundations is to be commenced. Excavation of foundations—(*contd.*).

8. As soon as a building has reached plinth level, the space between the masonry and the sides of the trenches is to be cleaned of all debris and filled with earth laid in 9″ courses and rammed.

9. As soon as the superstructure has reached 2′ above plinth level, the interior of the building will be filled up to plinth level with earth laid in 9″ courses, watered and rammed.

10. The ground in the immediate neighbourhood of a building will be cleared of all jungle, etc., and any hollows filled in. Trees will not be cut down without the order of the Garrison Engineer. The roots of any trees, etc., on the actual building site are to be grubbed up. Clearing and dressing sites.

11. On the completion of the building, the ground all round is to be carefully dressed and given an outward slope of 1 in 40. Where no gutters or downtakes are given, or where there are no pukka drains under the eaves, the plinth should generally be protected by the provision of rammed moorum, stone, or broken brick for a width of 3 ft. to 5 ft. all round the building.

12. All earth filling should be carried out in successive horizontal layers. In the case of large embankments etc., the following allowances should be made for subsequent settlement :— Earth filling.

In firm compact earth 1″ to 1¼″ per foot.
In ordinary loose earth 1½″ to 2″ per foot.
In black cotton soil 2″ to 3″ per foot.

MORTAR.

1. Portland cement must comply with the specification of the B. E. S. Committee : it should be obtained through the Director-General of Stores. Cement is supplied in barrels weighing 400 lbs. and containing 4·4 cub. feet. Cement.

2. Lime may be obtained either from stone limestone which generally yields a fat lime, or from kunkur which yields a more or less hydraulic lime. The best kunkur comes from deep beds and shows a blueish surface on fracture. Lime.

3. A design for a lime kiln is given in Plate III, Coal, charcoal or wood may be used for firing the kiln. The stone or kunkur will be broken to a 2″ gauge. The two following methods have been found successful :—

(*a*) Pack the metal in 3″ layers with ¼″ of coal dust between each layer. The burnt material should be drawn out every morning and replaced by fresh kunkur and charcoal at the top.

Lime—(*contd*.)

(*b*) Pack a layer of $4\frac{1}{2}$ feet of wood followed by alternate layers of 2 feet of metal and 2 feet of wood. Cover the top with mud plastered over, having a 2 feet diameter hole in the centre.

4. As a rule lime should be used within 14 days of its removal from the kiln : if it is stored it must be kept perfectly dry. Fat lime should be stored in an enclosed space in a large heap and the air excluded in every way possible, or it may be kept for many weeks in tanks if covered with water.

5. Lime may be either slaked, or ground fine in properly made mills (*vide* Plate IV). Before use it must be passed through a sieve of 64 meshes to the square inch.

Sand.

6. Sand must be sharp, clean, coarse river sand free from all admixture of earth or other impurities. For cement mortar, and if considered necessary for lime mortar, the sand must be thoroughly washed and screened through a sieve containing 64 meshes to the square inch.

Surkhi.

7. Surkhi must be made of burnt bricks or clay (free from over or under burnt particles) by grinding or pounding, and must be passed through a sieve containing at least 64 meshes to the square inch. It must be perfectly clean and free from any admixture of foreign matter.

Cinders.

8. Cinders can often be obtained from railways, pumping installations, etc., free of charge. Only clean clinker should be used, any wood ash being screened out. The cinders will be ground fine in a mill and screened as specified for surkhi. At Calcutta cinder mortar is composed of 1 part slaked Sutna lime, 2 parts sand, 2 parts crushed cinders : at Ambala, 1 part of slaked lime is mixed with 2 parts of crushed cinders, no sand being used.

Mixing lime mortar.

9. The mortar will be composed of lime, surkhi, and sand in various proportions according to the nature of the lime used, to be fixed by experiment for each station and approved by the C. R. E. In some stations cinders are used and occasionally it may be desirable to add a proportion of cement to lime mortar. The addition of surkhi to fat limes makes them more or less hydraulic.

10. The mortar will be mixed by measure, not by weight, on a clean platform close to the mill. For measuring, either brick bins or wooden boxes may be used. The ingredients will be turned over dry on the platform, placed in the mill, and water added as required, care being taken that too much water is not used : the mortar will then be ground for at least 4 hours, being stirred up by a beldar continually during the process. The blowing of lime can only be prevented by fine screening and keeping wet for at least 24 hours before it is used.

11. Lime mortar should be kept ready for use in troughs and in hot weather it should be covered over with matting. Mortar which has once set or which has lain for more than 24 hours on the ground must on no account be used for any work. When using kunkur lime for plastering, it is, however, better to leave it for some time to sour. **Mixing of mortar—(contd.)**

12. Cement mortar will be composed of cement and sand in varying proportions as may be considered most suitable for the particular work in hand. The quantity of water to be used in mixing should also be decided. The cement and sand will be thoroughly mixed together on a clean platform in a dry state until the colour of the cement is thoroughly distributed throughout the sand: after which the measured quantity of water will be added through a rose and the mortar thoroughly mixed. **Mixing cement mortar.**

Only a small quantities should be mixed at a time, and each batch should be used within 15 minutes of mixing.

CONCRETE.

1. Concrete will be composed of an aggregate of broken stone or other hard substance mixed with lime or cement mortar in the proportions found most suitable for each particular work and approved by the C. R. E. **Ingredients**

2. It is necessary that the mortar shall fill the voids in the aggregate: for concrete under flooring a 10 per cent. surplus of mortar is desirable. The quantity of the voids can be ascertained by thoroughly wetting the aggregate, placing it in a watertight box and noting the quantity of water necessary to fill the box: generally the voids amount to from $\frac{1}{3}$ to $\frac{1}{4}$ of the aggregate, if the aggregate is all of one size, but this may be considerably reduced by using an aggregate composed of stones of varying size. The most suitable proportions should be found by experiment at each station.

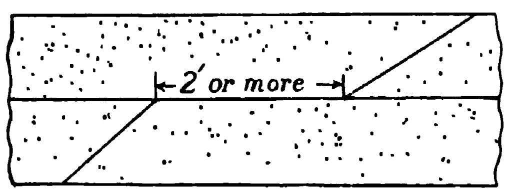
3. The proportions of cement, sand, and coarse aggregate in cement concrete will be specified in figures thus 1 : 2 : 4, which indicates 1 of cement, 2 of sand, 4 of coarse aggregate. Another method is to give the proportion of sand and aggregate to 1 of cement, thus 1 : 6 concrete means 1 cement to 6 of sand and aggregate.

4. The aggregate may consist of broken stone, thoroughly well burnt or overburnt brick, or gravel: it must be perfectly clean and free from all impurities, and have been soaked in water for at least 4 hours before being mixed with mortar. For concrete in floor roofs, etc., the aggregate should be of such a **Aggregate.**

Aggregate—contd.). size that it will pass through a $1\frac{1}{2}''$ ring and be refused by a $\frac{1}{2}$ inch sieve. For concrete in trenches, etc., the gauge may be increased to $2''$ for both lime and cement concrete. For reinforced work the gauges should not exceed $\frac{3}{4}''$ for ordinary work and $\frac{1}{2}''$ for moulded work, but should be evenly graded down to $\frac{1}{8}''$ stuff.

Mixing. 5. The aggregate, previously well soaked, will be measured and laid on a clean platform of brick, flagging or wood, of sufficient size to give ample room for mixing 8 to 10 cubic feet. The mortar will then be measured and laid on the aggregate; the whole will then be turned over until thoroughly incorporated.

Laying lime concrete. 6. Lime concrete must be used while quite fresh and should be laid in the work in courses of about $6''$ in thickness: each course is to be thoroughly rammed and consolidated before the next course is laid: the lower course should be clean and well watered before the next course is laid. Concrete must never be thrown from a height in large quantities.



7. When it is necessary to make joints in laying they should be arranged as shown in the margin.

8. No concrete is to be laid in the work after 2 P.M.: this is to ensure its being properly consolidated before nightfall and to prevent ramming the next day after the mortar has had time to set.

9. Concrete must not be laid of too fluid a consistency: no water should be added during consolidation, but the surface must be kept continually damp for at least 7 days.

10. Iron rammers weighing not less than 12 lbs. should be used and the ramming should continue until the lime has partially set or until a walking stick, dropped endways from a height, will rebound from the surface. Square headed rammers should be used for corners of trenches. With brick ballast wooden rammers may be used. Ramming is not complete till a skin of pure mortar covers the surface and completely hides the aggregate.

Laying cement concrete. 11. Cement concrete should be mixed in small batches and laid at once in the work. The concrete should be laid in layers not exceeding $6''$ in thickness. The whole work should if

possible be completed in one day: if it is found necessary to lay concrete on work that has already set, the old work should be wetted, hacked, and covered with cement grout. The surface must be kept damp for 14 days. Laying cement concrete —(*contd.*).

12. A 6″ layer of ordinary concrete will first be laid in the trench and rammed. On the top of this will be laid 3″ of concrete, on which will be bedded a layer of boulders. The top surface will then be levelled up with concrete and rammed. This process, exclusive of the original 6″ layer, will be repeated until the full depth is obtained. Care should be taken that the top of the uppermost layer of boulders is some 3 inches below the level of the finished concrete. Rubble concrete.

13. The boulders are to be cleaned and are to show no signs of decomposition. Each stone is not to be less in volume than $\frac{1}{12}$ cubic feet or more than 2 cubic feet. Every boulder will be at least 6″ from the stone next to it.

14 Specifications for this class of work are given in Specifications, rates, and notes on work, by Captain E. L. Marryat, R.E , 6th edition, pages 52, 53. Pisé and Béton Pisé.

Brick Burning.

1. Details of Bull's pattern kiln are shown in plate I. Brick burning

A circular plan is the best, but kilns can also be made straight or oval.

The dimensions given are for the most suitable size of small kiln, capable of burning 10,000 bricks daily, divided into 20 sections containing 14 concentric walls of bricks, and requiring one chimney.

Where it is required to turn out a larger number of bricks a broader kiln (up to 30′) may be built, requiring two chimneys.

2. In hard soil the trench may be unlined, with the bottom, sides and top edges dressed off to a true surface. In soft soil the walls will be of burnt brick of the dimensions shown in the figure Construction of kiln.

In damp sandy soil the excavation should not exceed 4′, leaving 3′ 6″ to bank up.

The damper spaces and combustion chambers as shown in figure 3 must be carefully marked out on both walls.

3. The chimney is 35′ high, mounted on a cast iron base plate on wheels, the axles of which radiate so that they will travel round the wall. They should run on a sheet iron pathway, and the gaps at the chimney openings require to be bridged as shown in figure 4.

Construction of kiln—(contd).

4. When two chimneys are used, the chimney openings on the inner sides will be opposite those on the outer but will be only 2′ 6″ in width, and the chimney will be only 25′ high.

5. The upper outlet into the chimney is controlled by an adjustable damper.

In the lower outlet from the kiln to the chimney the arch and its backing project 5″ to prevent the earth used for closing the outlet while working going into the kiln too far and thereby interfering with the draught.

6. Cross dampers, figure 5, are required to divide off the various sections of the kiln. These should be made 2″ smaller than the width of trench to prevent the centre key jamming. When fixing the cross dampers, great care must be taken to make them fit tightly. It is a good plan to drop a little dust or fine earth down behind them to close up any possible interstices owing to irregularities on the floor.

Loading.

7. The bricks should be thoroughly dried before being loaded. The method of setting the bricks is shown in figure 6. Care should be taken when loading to leave a space between the bricks except those spanning the combustion chambers. This space should not be less than ½″ in the bottom courses, decreasing to ¼″ in the upper ones.

The draught passage between walls increase as they get further away from the centre. The setting out is done with the aid of a templet such as shown in figure 7.

Only one wall can be exactly like the details shown, owing to the decrease in the distance between the lines of feed holes from the outer to inner walls of the kiln.

The bricks next to the combustion chambers from bottom to top and from side to side should, however, be exactly as shown.

8. There are five combustion chambers to each damper length. As each length is completed it is covered, except over the combustion chambers, with two layers of bricks laid flat breaking joint.

The feed holes are then formed with the aid of the templates shown in figure 8: there should be a feed hole over each of the two outer walls, after that over every alternate wall.

Nine inches of earth is then evenly spread to the top of the brick temporarily placed over the feedholes. This earth should be made as tight and impervious to air as possible.

9. Between the second and third and all subsequent lines of feed holes level bricks for ascertaining the settlement should be fixed. There should be one level brick for each pair of feed holes and from the settlement of each level brick will be known

when to close the pair of feed holes in front of it. The level bricks should be firmly bedded in the earth covering. Loading—(*contd.*).

10. To start the firing a temporary cross wall z^2, see figure 1, is built, with furnaces for bottom firing. Firing.

The chimney opening of the first section (a_1) is closed and the chimney fixed at the second opening (b_1). Cross dampers are put down at b_2, and c_2; and the chimney opening C, closed with a sheet iron cover provided for the purpose..

11. About 150 maunds of clean rubble coal is required for starting the firing of a 14 wall kiln and 250 for a 24 wall. For top firing good dust coal is required and should have a certain proportion of nuts or small rubble in it.

12 To meet all the varying conditions of temperature, damp floor or bricks, four sizes of ladle are required for top firing. These are given in figure 9.

13. When the fine coal will burn freely in the first line, it can be started, coal being given with No. 1 ladle at regular intervals of 15 minutes.

When there is a good bottom heat in the first line, fire the second with No. 1 ladle and the first with No. 2. When there is a good bottom heat in the second line, fire the third line with No. 1 ladle, the second with No. 2, and temporarily stop firing the first, except the two outer feed holes. Take on the 4th line in the same way temporarily dropping the 2nd. When there is a good bottom heat in the 4th line, take on the 5th with No. 1 ladle and fire the whole of the other four with No. 2 ladle.

Up till this the bottom firing should under no circumstances be pushed, but now it should be cautiously increased. This, being the critical time, should if possible be in the day time.

If No. 2 ladle does not seem to give sufficient heat after closing the bottom firing, use No. 3 or even No. 4 ladle: this will only be necessary in cold rainy weather.

14. If intelligence is used, by the time there is a good bottom heat in the fifth or front line, the second line from the front will be the hottest, and the back line can, all but the two outer feed holes, be closed.

If at the same time there is a settlement between the first and second lines, or between the second and third of say an inch or an inch and a half, slacken down the bottom firing but do not close it altogether until two or three lines are closed finally.

For opening a fresh line in front two conditions should always be fulfilled: there must be a good bottom heat in the front line, and the heat in the second line from the first must be greatest.

Firing—(contd.).

At this time, with the bottom firing slackened down and one line of feed holes closed, great judgment should be used as to the sufficiency or otherwise of the wave of heat. If from a deficiency of settlement or from the appearance when looking down the feedholes there seems to be insufficient heat to thoroughly burn the bricks the firing should be increased. As long as the bottom firing is still going on absolute control is retained.

15. Having by the time the 2nd or 3rd line is closed got a thoroughly sufficient wave of heat, stop the bottom firing entirely. Close the furnace mouths entirely and the ashpit mouths rather loosely, leaving interstices in the latter equal in the aggregate to 3 square inches in each.

When a line in front is opened, one behind should be ready to close. If however it is seen from the settlement that this is not the case there is no harm in delaying the opening a little.

The kiln will now be in full working order, the chimneys and dampers having been moved on as required.

16. Take out the first cross damper when there is a good bottom heat in the first line, *i.e.*, the 8th from the chimney, and fix it in next vacant line. The chimney is moved on when the bottom heat has got as far as the fifth row from it.

17. The adjustable damper should be lowered three bricks, when the bottom heat is 7 lines from the chimney, and all but one brick removed, when the bottom heat reaches 6 lines from the chimney.

It is closed down entirely when the chimney is moved, and the outlets are blocked.

After moving the chimney, the upper and lower outlets being open, a strong draught is created which prevents the bricks vitrifying owing to stoppage of draught at the current when heat is maximum, and the draught at the combustion chamber is kept uniform.

18. It is important that the working of the kiln should be as regular as possible, and a five line chamber should be worked to daily.

Unloading.

19. When twelve damper lengths have been burnt off, the temporary cross wall can be taken down and unloading commenced. Before doing this a cross damper should be fixed at two dampers lengths from the end.

Finishing burning.

20. When it is desired to finish off burning, a cross wall similar to that constructed at starting but without the furnaces should be run up at the end of any convenient chamber 6″ from the bricks.

Resting half on this and half on the green bricks, build two dummy chimneys 5′ long and 6′ high of bricks and plastered with mud. Finishing burning—(*contd.*).

When the time for moving the chimney from its last possible position has arrived, these two dummy chimneys, which up to this should have been closed at the top, should be opened, and will finish off the burning.

21. These are worked in a somewhat different way. No furnaces are required for starting, wood is packed to a depth of 3′ in a combustion chamber 1′ wide, and lit through fire holes 9″ square at the bottom of the wall. Wood fire kiln.

Every alternate feed hole only goes down half the depth of the kiln, the object being to increase the heat near the top. The feed holes should be not less than 14″ square.

22. When a sufficient length has been loaded, the wood in the combustion chamber is lighted. When the wood is nearly burnt away, top firing is started into this chamber only, and continued until the bricks forming the first line of feed holes are sufficiently hot, when regular top firing will be commenced.

The chimney can be kept two or three lines further away from the burning, than in the case of coal firing.

22. When dry wood is procurable this method of starting a kiln may be used with advantage for a coal fired kiln, and the furnace bars saved.

Brickwork.

1. First class bricks will consist of stock-made bricks of uniform size, shape and colour, and thoroughly well burnt. Each brick must be free from defects, quite straight and rectangular, ring clearly when struck and be perfectly sound in all respects. No brick should absorb more than $\frac{1}{6}$th of its weight when soaked in water. The usual size of a brick is $9'' \times 4\frac{3}{8}'' \times 2\frac{3}{4}''$. Bricks.

2. Second class bricks will only differ from 1st class bricks in that the colour and shape need not be so good or uniform.

3. Third class bricks may include overburnt and distorted bricks, but never underburnt or "pila" bricks. Under this class come kumhar or Country bricks which must be well burnt and thoroughly sound and should not be smaller than $8'' \times 4'' \times 1\frac{1}{4}''$.

4. Sundried bricks will be made from stiff clay thoroughly worked up, exactly in the same way as for 1st class bricks; for good work they should be sand-moulded, for inferior work slop moulding will do.

5. Burnt bricks may be laid in cement, lime or mud mortar sundried bricks will be laid in mud mortar. Mortar.

Mortar—(*contd.*). 6. Cement and lime mortar will be prepared as already specified. The cement mortar will ordinarily be composed of 1 part cement to 3 parts sand.

7. Mud mortar is to be prepared from stiff clay, which is to be broken up into a fine powder and feed from grass, stones, etc. It will then be mixed with water on a clean platform and worked up to the consistency of clay for brickmaking. Before use it will be gradually thinned with water until it assumes the consistency of mortar. If necessary sand or chopped straw may be added at the discretion of the Assistant Commanding Royal Engineer to prevent excessive shrinkage. Holes, if dug near buildings, must be filled in; the Garrison Engineer will indicate the places from where mud is to be obtained. Good mortar can be made out of black cotton soil, if sufficient sand is added.

Laying. 8. All brickwork will be laid in "English" bond (*vide* plates V, VI) and no half bricks or bats are to be used except where necessary to complete the bond.

9. All bricks that are to be laid in cement or lime mortar must have been soaked in water for at least 2 hours before being put in the work.

10. Each brick is to be thoroughly well bedded and flushed in mortar. Joints are to be of uniform thickness, not exceeding $\frac{1}{4}''$, $\frac{3}{8}''$ and $\frac{1}{2}''$ for 1st, 2nd and 3rd class brickwork respectively. Each course is to be quite level and in perfect bond.

11. 1st, 2nd and 3rd class brickwork are the same as regards specification, except as noted for thickness of joints. The class depends on the shape and quality of the bricks. Also in 1st class brickwork the vertical joints must be quite symmetrical and truly plumb. In every case precautions must be taken to ensure careful handling of bricks by coolies and cart-men, otherwise the edges and corners will get destroyed.

12. Where pointing or plastering is specified, joints will be raked out the same day: where no pointing or plastering is specified, the joints will be neatly finished off flush with the face of the wall.

13. The brickwork must be carried up truly plumb and evenly throughout a building: no step, left temporarily during construction is to exceed 8 courses in depth. When brickwork in one portion of a building has to be delayed, the work must be raked back in regular steps, one course each.

14. The joining on of new work to old requires a good deal of care, as the new work is bound to settle and cause a crack. When time is no object, the new work can be done in sections

of a few feet at a time, and the next section should not be begun until the first has dried out. Setting in cement with fine joints, stone bonds, etc., have been satisfactorily used. Another method is to cut a vertical groove in the old masonry and to build the new masonry with a tongue fitting into the groove: this method can be used with 1st class pointed work or where sundried masonry is joined to a burnt brick wall. Laying—(contd.).

15. Care must be taken that as the work proceeds, all iron and stone fixtures, etc., are built in and pockets left in positions as directed.

16. Walls as they progress are to be kept thoroughly well watered on their faces and tops: when work is left off at night, a fillet of mortar about $1\frac{1}{2}''$ high will be made round the edge of the last course laid, so as to form a trough, which will be filled with water. Keeping wet work in lime or cement mortar.

17. All new work must be kept watered and damp for at least 7 days. Old work is to be kept wetted and saturated for 2 days before any new work is put on it.

18. This construction is only to be adopted for inferior buildings or in a dry climate. Care must be taken that the sundried and burnt bricks are of the same size, that the joints are of the same thickness and that the unburnt and burnt brickwork are bonded together in the work. The sundried bricks used must be absolutely dry. The top two or three courses of a wall must be of burnt brick in lime, and where loaded beams or trusses rest on the walls, pillars of burnt brickwork must be built up from the foundations. The height of walls of this type should not exceed 18 feet. Sundried walls faced with burnt brick.

19. For honeycomb work fine lime mortar must be used, and the bricks must have a bearing of $\frac{3}{4}''$ on each side, so that the opening will measure approximately $3'' \times 3''$. The joints must be struck flush so as to give an even surface on all sides. Honeycomb work.

20. Hollow walls of brick in lime or cement mortar may be used in certain situations, such as magazines and walls exposed to driving rain or to great heat. The outer wall will usually be $4\frac{1}{2}$ inches thick, and should carry no part of the load. The outer and inner faces will not be more than $2''$ or $3''$ apart. Hollow walls.

21. The outer and inner faces are to be connected by cast iron or wrought iron cramps $9''$ long with splayed ends: or $\frac{1}{16}''$ hoop iron may be used, the ends being punched to give a grip. The cramps should be bent or twisted in the centre in order to stop the passage of water, and should be tarred and sanded. Cramps should be spaced not more than $2\frac{1}{2}'$ apart horizontally or 4 courses apart vertically: the cramps in successive courses

Hollow walls —(*contd.*). should break joint. Extra cramps are to be given near corners and openings.

22. Mortar is to be prevented from falling down into the hollow portion of the wall by means of twisted bands of hay laid longitudinally: these are to be removed as the work proceeds.

23. The top foot is to be built solid and also $4\frac{1}{2}''$ on either side of openings. No putlog holes for scaffolding will be allowed in the outer skin.

Hooped Brickwork. 24. Partitions may be built economically of hooped brickwork in cement, half a brick thick, or in the case of small partitions, the bricks may be laid on edge.

25. The hoop iron will be built in and secured to the main wall at its junction with the partition. At corners care must be taken to join securely the strips of hoop iron on either side. Hoop iron not less than $\frac{1}{16}''$ thick may be used also in lime mortar for walls not exposed to the weather.

26. The hoop iron should be tarred and sanded and care must be taken that it is everywhere embedded in the mortar and not exposed to the action of the air.

Arches. 27. In building arches, concentric rings are not to be used; each course of the arch must be regularly and systematically bonded (*see* plate VI).

28. All bricks for each course of an arch must be regularly and carefully summered; when practicable special bricks should be moulded and burnt for arches. Where the amount of work is small, the summering may be effected by cutting and grinding; the whole of the bricks for any particular arch are to be prepared on the ground.

29. Before the building of an arch is commenced the skewbacks and the whole of the bricks for the work will be passed by the subordinate in charge.

30. Lime mortar for arches is to be ground specially fine. No joint in an arch is to exceed $\frac{1}{4}''$ in thickness and must be of the same thickness throughout the course.

31. Centerings must be stiff and are to be struck within 24 hours of the completion of a segmental arch, but in the case of semi-circular, semi-elliptical or pointed arches, not until the adjacent brickwork has reached two-thirds of the height of the arch.

Scaffolding. 32. All scaffolding should usually be double, *i.e.*, there must be two sets of uprights. Care must be taken that only headers, and not more than one header per putlog, are left out for the

scaffolding. The height of the scaffolding must be kept within a few feet of the top of finished work. Scaffolding —(contd.)

Stone Masonry.

General.

1. The stone to be used will be taken from quarries specified by the Garrison Engineer. It should be hard, durable and tough, and each stone must be laid, when in the work, on its natural quarry bed. For illustrations of stone masonry see plates VII, VIII.

2. The specification for brickwork as regards mortar, laying, keeping wet, and scaffolding will apply, except as otherwise provided for below.

Ashlar work.

3. Generally for all ashlar work the Garrison Engineer will supply the contractor with the exact dimensions of each stone, or with a plan of each course of masonry showing the necessary dimensions.

4. Ashlar work will have its beds and joints finely dressed, free from any winding, and true and square in every respect. Joints are not to exceed $\frac{1}{4}$ inch, and must be perfectly level and true.

5. The outer face or faces may be rock-faced, finely chisel-dressed, rock-faced with chisel margin, rock-faced with chisel margin and chamfered edge, or as may be described by the Garrison Engineer.

6. Ashlar work shall never be laid in courses of less than 10 inches in height; one-fifth of the face should be headers, and no stone should have a less width of bed than $1\frac{1}{2}$ times its height.

7. When ashlar quoins or ring stones are provided, the arrises must be dressed, clean, sharp, true, and free from all winding; for quoins quite plumb and vertical, and for ring stones lying exactly in the line of the perimeter of the circle indicated.

Coursed Rubble.

8. Coursed rubble will be laid in courses varying in height as may be most convenient and economical, according to the nature of the stone procured from the quarry, as regards the depth of the natural bed of the stone or the manner in which it will be cleaved, but no course will ever be less than $4\frac{1}{2}$ inches, or more than 9 inches in thickness.

9. Coursed rubble may have its courses either of equal or unequal height; but in the latter instance the deeper courses must be laid towards the bottom of the structure, and may

Coursed Rubble—(*contd.*).

gradually get shallower within the limit given above, as the wall progresses in height.

10. Buildings constructed with coursed rubble masonry may be supplied with ashlar quoins of the height of one or two courses, and care should be taken, when equal courses are specified, that the height of the wall is divided into an exact number of courses, and an exact number of quoins.

11. Joints are to be as for ashlar work but may be half an inch thick. No joint must overlie another less than $4\frac{1}{2}$ inches, measured on the face of the wall.

12. No stone must be used which is less than half a cubic foot in size, its bed must not be less than $1\frac{1}{2}$ times its height, and care must be taken that the interior of the wall is carefully constructed with proper sized stones set in mortar and not filled up with spalls and chips.

13. In each course there should be a bond stone at every five feet. In walls of $2\frac{1}{2}$ feet thick or under, the bond stone must be one stone; in thicker walls two stones overlapping at least 9 inches may be used.

Random square course rubble.

14. This description of masonry will be coursed every 18 inches in height, and will have quoins of equal or unequal height, but there must be two quoins to every 18 inch course—see plate VII.

15. Each course will be made up of unequal sized stones, dressed perfectly square and true to whatever size is possible from its dimensions as it comes from the quarry. Joints will be as for coursed rubble.

16. Two stones may have their joints immediately over one another, but the third stone should always overlap at least $3\frac{1}{2}$ inches. One fifth of the face of the wall should consist of through headers. All other stones should be in half bond, or should overlap each other at least one-third the thickness of the wall.

17. No stone must be laid whose bed is not at least $1\frac{1}{2}$ times its height.

Random coursed rubble.

18. For this description of masonry see plate VIII. Each stone will be hammer dressed to the number of sides to which it can be most conveniently dressed, and will then be fitted into the wall so that the joints shall never exceed half an inch throughout. The vertical joints of each course must break joint at least 3 inches with those of the courses above and below it, and no face is on any account to be narrower or shorter than

its height. If it be of irregular shape its length at right angles to the face of the wall must be at least $1\frac{1}{2}$ times its height. **Random coursed rubble—** ***(contd.).***

19. Random coursed rubble masonry should be supplied with equal or unequal quoins, and should be coursed every 18 inches, one-fifth of the face should be through headers, and no stone should be less in depth than $1\frac{1}{2}$ times its height, every stone being well flushed in mortar as described for masonry under other heads.

20. All stones which are not headers shall half bond or overlap with one another, at least one-third the thickness of the wall, and the quoins may be either of equal or unequal height; but there must always be two quoins to every 18 inch course.

21. The stones will be laid at random without being brought up to any level courses, each stone will be laid on its quarry bed, will be bedded in an ample supply of mortar, and will be wedged or pinned strongly into its position in the wall by spalls or chippings which may show on the face. **Random uncoursed rubble.**

22. No fixed rule can be laid down for sizes of joints, but they must be kept as small as possible. This work is subject to the same rules for through or bond stones as specified above for other classes of rubble masonry.

23. River boulders and large pebbles may be used for this sort of work, either laid in their natural forms, or split, and their fractured surfaces shown on the face of the work.

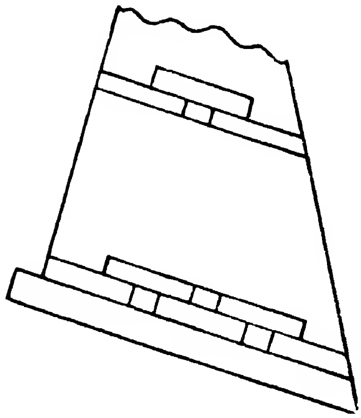
24. When walls are built of this material, bands of brickwork, or masonry of a more regular description should, at fixed vertical intervals, run through the whole thickness of the wall, to assist in tying it all together.

25. All the above kinds of masonry can be carried out dry, that is without the use of mortar. This sort of work is in very general use for breast and retaining walls in hill roads. **Dry rubble.**

26. In these cases the front batter should never be less than $\frac{1}{4}$. The back slope should be about $\frac{1}{6}$. The coursing will always be normal to the front face of the wall, and there will always be a projection or broad footing at the base. The top of the wall must not be less than 2 feet thick. In surcharged walls this thickness must be increased to 3 feet.

27. Through bond front to back, consisting of a single stone or of several stones put together, must be given in every course at every 5 feet along the face of the wall. Where bond stones of length equal to the thickness of the wall are procurable, they are always to be used.

Dry rubble—(*contd.*). 28. In thickness beyond this limit the through bond will be given as shown in the marginal sketch. Care must be taken that the spanners bear normally on the other stones, so that with the superincumbent weight, they may act truly as binders.



29. The limit of height for such walls will depend on the quality of the stone, and on the space available at the base. Dry stone walls can be 16 feet in height if carefully made. Above this height bands of lime masonry both vertical and horizontal, 2 feet to 4 feet wide, placed at varying distances according to the nature of the soil and weight behind, should be given.

30. The filling immediately behind the wall should consist of stone refuse and chips. Earth is not to be used if it can be avoided. Suitable arrangements for drainage must be made

Dry stone pitching. 31. Stones will be not less than 10 inches long by 6 inches wide by 6 inches thick. The faces are to be roughly squared, and all interstices are to be filled in with chips, etc., as the work proceeds. The backing is to be filled in behind the pitching as the latter proceeds.

Dressed stone. 32. The stones will be obtained from the quarries specified by the Assistant Commanding Royal Engineer: they will be cut and dressed to the exact size of the drawings, faces to be true and square. For bed plates, fencing posts, etc., the stone is to be chisel dressed: for pillars, etc., the stone, if so ordered, will be fine tooled.

Pointing.

Preparing walls. 1. When pointing is specified, all joints are to be raked out to a depth of ½″ before pointing is commenced.

2. No pointing is to be begun until the walls have been passed as ready for it by the officer in charge.

3. The face of walls to be pointed must be cleaned down and kept thoroughly wet for at least 2 days beforehand. All dust must be brushed out of the joints after raking out old work.

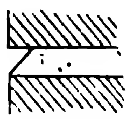
Mortar. 4. Lime or cement mortar may be used.

5. Lime mortar may be made as specified under that head, but should be further ground in small hand "chakkis" until there are no lumps or grit in it.

6. Cement mortar will be composed of 1 part cement and 1 part sand, or as may be directed. **Mortar—(contd.).**

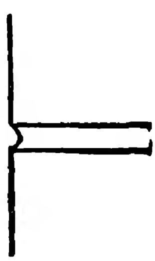
7. The mortar will be placed in the joints, well pressed in, and made smooth and flush with the surface of the wall, care being taken that it is not allowed to spread over the masonry. **Applying.**

Section of horizontal joints



8. The horizontal joints will then be struck back with the trowel along the upper edge as shown in the sketch. The vertical joints should be struck semi-circular or V shaped by means of an iron tool, $\frac{1}{4}$ inch diameter. For interior work, which is not to be plastered, the joints should be finished flush as the masonry proceeds.

The sketch in the margin of the book showing the section of horizontal joints is a "struck weathered joint" for use with brick masonry and is useful in situations exposed to beating rain and with indifferent mortar.



In most cases the ordinary "struck joint" with the mortar hardly indented at all is recommended.

The section of this joint is shown in the sketch.

When ordinary stone masonry is pointed the mortar should simply be struck off with the trowel and left so, showing frankly such irregularities as are produced by the corresponding irregularities of line and surface of the stones themselves. No groove or line to be made in the mortar.

Plan of vertical joints

9. The work will be kept thoroughly wet for at least 3 days in the case of lime pointing and 10 days in the case of cement pointing. **Keeping wet.**

Plaster.

General. 1. Walls will be prepared as for pointing. Walls may be plastered with lime, cement or mud plaster, as may be ordered. The plaster may be applied in 1, 2 or 3 coats, but no single coat should ever exceed $\frac{1}{2}''$ in thickness. On very rough walls a preliminary coat must be given to fill up hollows before the first plastering coat is laid on.

2. Before work is started patches of plaster $6'' \times 6''$ should be put on about $10'$ apart as gauges: by this means an even thickness will be obtained. Cement plastering must be in squares or strips, or cracks will appear if a large surface is done.

Lime plaster 3. Lime plaster will consist of mortar made as specified under that head, or as may be specially ordered. First class lime plaster will consist of 2 coats and a rendering coat. Ordinary plaster will consist of one or two coats, with a preliminary coating if necessary; on brickwork one coat only is necessary as a rule. With stone or slow slacking limes it is essential for the lime to be finely screened and kept wet, or better actually under water, at least 24 hours before plastering is commenced, otherwise blisters will appear. The addition of 10 lbs. of gulgal (gum) boiled in water to every 100 cubic feet of mortar improves the plaster. A small quantity of hemp, chopped up small, is often added to the mortar and well mixed by beating with hammers. Fat limes make the best plaster as any unslaked nodules in hydraulic lime will cause blisters.

4. The mortar will be applied by trowels and will be well pressed into the joints until the necessary thickness usually $\frac{1}{2}''$, has been obtained. It will then be beaten with long thin laths until such beating makes no impression on the surface. If it is desired to quicken the setting of the mortar, the walls may be sprinkled during beating with a mixture of $3\frac{1}{2}$ seers gur (coarse sugar) dissolved in 20 to 30 gallons of water and 2 seers of bael fruit (wood apple) added: this improves the quality of the plaster.

5. Each coat must be allowed to set before the next is applied and the surface should be left rough and freely scored over with the edge of a trowel, to give a key for the next coat.

6. The final surface will, when it has become quite firm, but before it has set, be floated by means of a straight edge drawn backwards and forwards until quite smooth. If necessary a sufficient quantity of fine plaster will be thrown on the wall during the process.

7. If so ordered the surface, when perfectly dry and set, will be "rendered" quite smooth by having lime "putty" spread

over it with a large trowel and rubbed until smooth and even. A surface finished in this way should be so smooth as to leave no impression of grit when rubbed with the thumb nail. **Lime plaster —(contd.).**

8. The plaster will be kept wet for at least 5 days.

Cement plaster. 9. Cement plaster will be applied as specified for lime plaster. The thickness of the plaster and the proportion of cement to sand will vary with the particular work. The plaster is to be applied within 15 minutes of being mixed and must be kept wet for at least 10 days. The surface is to be polished smooth by means of polishing stones or trowels; mortar composed of pure cement or 1 cement to 1 sand may be applied during the process if necessary.

10. If large surfaces are to be dealt with, such as racquet courts, it is advisable to fix vertical wooden screeds to the walls 4′ apart and to apply the plaster in alternate sections; when the plaster has thoroughly set the screeds are removed and the intermediate layers filled in. In the case of small reservoirs it is best to complete the whole of the internal plaster in one operation if possible. Cement plaster may be rendered waterproof by the addition of 8-12 per cent. of lime to the weight of cement used.

Mud plaster. 11. Will be composed of stiff clay, to which will be added, if ordered, an equal bulk of chopped straw or pine needles. In certain cases it may be necessary to order the addition of sand. Black cotton soil will make a good plaster if plenty of sand is added.

12. The clay after being excavated will be spread out in the sun and powdered; the chopped straw or pine needles will then be added and thoroughly incorporated in the dry state with phowrahs. Water will then be added and the whole left for 2 days to soak. It will then be mixed by phowrahs and treading, water being added as required until the consistency of stiff mortar is obtained.

13. The plaster will be spread evenly over the surface to the thickness ordered, usually 1″ on roofs, $\frac{1}{2}$″ to $\frac{3}{4}$″ on walls, and be floated with a straight edge until the surface is perfectly smooth, true and level. Any cracks that open out during drying are to be filled with liquid cowdung.

Leeping. 14. When the mud plaster has dried it will be leeped, with a mixture of cowdung, clay, and, if necessary, sand, applied by hand on roofs and with trowel and float on walls.

15. The cowdung is to be prepared by steeping it in water to free it from grass, straw and other impurities; if found necessary, it should be passed through a fine sieve to exclude seeds. One cubic foot of finely powdered clay is added to every cubic

Leeping—(*contd.*). foot of cowdung and the whole mixed in a tub and thoroughly incorporated.

Pargetting. 16. The insides of chimney flues will be plastered with a mixture of 3 parts cowdung to 1 part lime mortar.

White and Colourwash.

Preparation of walls. 1. The walls are to be thoroughly cleaned down and freed from all foreign matter, and loose flakes of old whitewash: any patches of damaged or loose plaster are to be hacked off and replaced. If so ordered, the walls will be scraped in order to remove the old whitewash. If whitewashed walls are discoloured by smoke, it is advisable to give a wash of a mixture of wood-ashes and water, before a new coat of whitewash is given. Walls should be scraped with a special tool made of a flat iron triangle, 4 inch side, with a handle in the centre: the tool is worked with a downstroke.

Whitewash. 2. The wash will be prepared from shell lime, when available, otherwise from fresh stone lime slaked on the spot.

3. The lime will be placed in tubs: water will then be added, mixed and stirred until it attains the consistency of thin cream: it will then be strained through a coarse cloth into earthen pots or other receptacles. Gum in the proportion of 4 ounces to one cubic foot of lime will then be added and the whole boiled together. If considered necessary, the proportion of gum may be increased and rice size added or used instead of gum.

4. The wash will be laid on with a brush, each coat consisting of one vertical, followed by one horizontal stroke: each coat is to be allowed to dry before the next is applied. Three coats will be given for new work.

Colourwash. 5. Will be usually prepared by adding the necessary colouring matter to the strained whitewash. Only sufficient wash for the day's work will be prepared each morning.

6. A suitable buff colourwash for external use may be prepared in the following way:—

(*a*) Slake 4 lbs, of lime with 16 pints of water.

(*b*) Dissolve 10 oz. of ramraj (brown earth) in 2 pints of water.

(*c*) Boil 2 oz. gum in 1 pint of water.

(*d*) Boil 4 oz. rice in 3 pints of water.

After the lime has slaked, strain all the above through a cloth into a non-absorbent tub or drum.

7. A suitable pale green colourwash may be prepared as follows:— Colourwash—(*contd.*).

(*a*) Slake 4 lbs. of lime in 18 pints of water.
(*b*) Boil 7 lbs. of fresh mango bark in 4 pints of water for 2 minutes.
(*c*) and (*d*) as in paragraph 6.
(*e*) Boil 2 lbs. tootya (blue stone) in 3 pints of water.

After the lime has slaked and the tootya partially cooled, strain all the above in the order given into a non-absorbent tub or drum thoroughly mixing the ingredients in the meantime: the liquid should then be again strained to remove any lumps that may have formed.

8. Walls will be prepared as specified for whitewash. Walls that have previously been colourwashed another colour will be first whitewashed until the original colour has been obliterated. In new work the walls will be first given 2 coats of whitewash, which must be allowed to dry before the colourwash is applied.

9. Colourwash will be applied in the same way as whitewash. The wash is to be stirred continually during use. To test white or colourwashing when finished, rub with the fingers. If the surface is powdery and comes away readily, or if the general appearance is streaky, the work should be rejected.

10. Distemper should be used for internal work. Good results can be obtained with Shalimar or Hall's distemper or Muraline. Muraline has the greatest covering power; Muraline and Shalimar are easier to work than Hall's. A priming coat should be used with distempers, if recommended by the makers. The priming coat may be of ordinary size, made by boiling glue in water. Distemper

11. On new walls 2 coats of distemper should be given over 1 coat of priming, on old walls 1 coat of distemper should be sufficient. Good distemper will not rub off when tested with the fingers ten days after completion.

12. Distemper should only be applied on thoroughly dry walls and in dry weather: hard stiff brushes should be used. Distempered walls should only be washed in dry weather.

FLOORS.

1. The plinth filling will be watered and rammed in 6″ layers until thoroughly consolidated; a sufficient quantity of earth will then be removed and the surface levelled off to the height shown in the plans. Inner floors are to be perfectly level and verandah floors are to be given an outward slope of 1 in 40. Plinth filling.

Plinth filling —(*contd.*). Old brick from demolitions form an excellent filling, if properly rammed.

Terraced flooring. 2. Should not be less than 6″ thick. It will consist of lime concrete prepared as specified under the head concrete, except that the gauge of the aggregate should not exceed $1\frac{1}{2}$ inches.

3. It will be laid on the floor to the thickness specified, usually 6 inches, and be beaten with heavy rammers as used for foundations until consolidated. The surface will be frequently tested and kept perfectly true and even.

4. As soon as the mortar has thoroughly come to the surface, the ramming is complete, and the mortar will be smoothed and rendered with the trowel, sprinkling it with water if necessary. The surface will then be fairly polished, a little lime putty being used during the operation, but no plaster is on any account to be laid over the concrete.

5. During the process of ramming and polishing, the surface will be liberally sprinkled with a mixture consisting of $3\frac{1}{2}$ seers gur (coarse sugar) and 2 seers of bael fruit (wood apple) dissolved in 20 to 30 gallons of water.

6. After the surface has been polished it will be covered with 2 inches of fine sand or grass and kept damp for 21 days.

Brick and Tile flooring. 7. This form of floor will consist of 1st class bricks, either flat or on edge, or of tiles laid on 3″ of lime concrete. Before the concrete is laid, the surface below must be passed by an officer.

8. The lime concrete will be rich in mortar, as the same amount of compression when ramming cannot be obtained as in foundation work. It will be laid as specified under "Concrete," care being taken that the surface, when completed, is truly level and uniform and that any slopes shown in the drawings have been allowed for. The concrete bed will be passed by an officer before any bricks are laid.

9. The bricks before use must have been soaked in water for 4 hours. They will be laid in lime mortar, true and level, either in parallel rows breaking joint or in herring-bone bond, and all joints must be true and parallel. The joints are not to exceed $\frac{1}{16}$th inch in thickness, the sides of the bricks being rubbed as necessary. Care must be taken that the sides are worked square with the face of the brick, and not tapering downwards to give a false joint on top.

10. The joints will be finished off flush and no mortar must be allowed to spread over the bricks. If cement pointing is specified the joints will be not less than $\frac{1}{4}$ inch in thickness,

and will be raked out while the mortar is still damp and the floor will be pointed as specified under pointing. Brick and Tile flooring —(*contd.*).

11. The floor must be kept wet for 7 days after laying, 10 days if cement pointing has been done.

12. This will consist of the best stone locally procurable on rammed earth and 3″ lime concrete as specified for brick floors. Flagged flooring.

13. The flags may be of unequal sizes, but must be hard, even, sound and durable. They will not be less than $1\frac{1}{4}''$ in thickness, never less than 14″ wide or greater in length than $2\frac{1}{2}'$. For machine shops and stores, larger and thicker flags are required, on 4″ to 6″ of lime concrete. The flags will be dressed true and square, both on the upper surfaces and on the faces of their edges, to which latter on no account must a wedge shape be given. Flags projecting over the edges of verandahs or steps will have their outer edges neatly "nosed."

14. The flags will be well soaked in water before being laid, and will be well bedded in mortar so that the whole slab rests on mortar: by tapping with a hammer places not properly bedded can be detected. The floor, when finished, will be kept wet as specified for brick floors. No cross joints in adjacent courses shall be less than 8″ apart. Courses are to be of uniform width parallel to the shorter side of the room.

15. When such floors are cement pointed, the stones should be laid against wood or iron slips of uniform thickness, so as to form joints not less than $\frac{1}{4}''$ wide. After each row is laid the slips are removed, and the open joints at once filled in with Portland cement mortar 1 to 1, the surface of the pointing being if anything below the top of the stones.

16. This type of floor will consist of $\frac{3}{4}$ inch to $1\frac{1}{2}$ inches of cement concrete laid on lime concrete over rammed earth as specified for brick flooring. Special care must be taken that the filling under the lime concrete is wetted and thoroughly consolidated, or the whole floor will be liable to crack. Cement concrete flooring.

17. In new work the cement concrete must be laid before the lime concrete has set. The surface of the lime concrete must be thoroughly clean and must be moistened before laying the cement concrete.

18. The cement concrete will be prepared as specified under that heading. The aggregate will consist of hard stone broken and graded from $\frac{1}{8}$ inch to $\frac{1}{2}$ inch. The best proportion of cement, sand, if any, and aggregate must be determined by experiment: but generally 1 of cement to $2\frac{1}{2}$ or 3 of graded aggregate will be found suitable.

Cement concrete flooring —(*contd.*).

The following mixture has been successfully used at Bombay:—

1 of metal $\frac{3}{4}''$ gauge: 1 of shingle pea size and smaller: 1 sand: 1 cement.

At Bareilly 7 of metal, $\frac{1}{2}''$ gauge and smaller: 3 of bajri: 4 of cement.

At Calcutta cement concrete consists of 1 cubic foot of cement to $2\frac{1}{2}$ cubic feet of hard stone, not exceeding $\frac{1}{2}$ inch gauge: $\frac{5}{6}$ths of the cement is mixed with the stone, while the remaining $\frac{1}{6}$th is sprinkled on after ramming, and trowelled in.

At Jabalpur, cement concrete floors were made by first thoroughly consolidating 4$''$ of dry stone metal $1\frac{1}{2}''$ gauge: on this was laid $\frac{3}{4}''$ of cement concrete, consisting of 1 cement to 3 of sand to 6 of broken stone $\frac{1}{2}''$ gauge, followed by a similar layer of concrete composed of 1 cement to 2 of sand to 4 of aggregate. A finishing layer about $\frac{1}{2}''$ thick of cement plaster, 1 cement to 2 of sand, was then put on: the whole operation, apart from the ramming of the dry metal, being completed in a few minutes.

19. Large areas of cement concrete are liable to crack, due to contraction during setting. To prevent this it is advisable to divide the floor, either into strips extending across the width of the room or into squares or rectangles: the width of each strip, etc., should be from 4 to 8 feet.

20. The edge of each section into which the floor is divided *should be defined by flat bars of steel or wood, their depth* being the same as that proposed for the finished floor; they should be whitewashed, in order to prevent their adhering to the concrete. Adjoining sections of the floor should be completed on different days.

21. The cement concrete, which should not be too dry, will be used immediately it has been mixed and spread evenly, using a straight edge to insure this; it will be at once well beaten with 5 lb. wooden "thaupies."

22. Different men must be employed for each of the operations of mixing, spreading and beating, so as to keep them continuous. As many men should be employed beating as there is room for: the labour costs little compared to the cement, and it is very important that the consolidation should be carried out quickly. The work is best done departmentally to ensure careful work.

23. The concrete is to be beaten until the mortar comes to the surface, which should be in less than 15 minutes from the

time of commencing the mixing. It must be remembered that cement sets quickly, and the work is spoilt either if the beating is continued too long or is not sufficiently thorough. Cement concrete flooring —(contd.).

24. When the mortar has come to the surface, the floor will be polished with trowels; the men engaged on this sit on small boards on the new floor if they cannot reach the work otherwise.

25. The joints between the sections will be filled in with a mixture of 1 of cement to 2 of sand, and finished in the same way as the rest of the surface.

26. If it is desired to fine polish, when the concrete has set the surface will be rubbed over with small hard polishing stones: if found necessary neat cement can be sprinkled on sparingly through a pepper pot.

27. If it is desired to colour the floor the following materials will be mixed with every cubic feet of the mortar used for the top surface.

Red. One twelfth cubic foot red oxide of iron powder, (obtainable from Olpherts Paint Works, Katni): or in certain cases red earth may be used.

Black.—One sixth cubic foot Manganese dioxide.

Buff.—One sixteenth cubic foot ochre or pila matti.

28. The surface of the floor will be covered with 2 inches of grass, sand or sawdust, and kept wet for from 7 to 14 days according to the state of the weather. If possible the floor should not be taken into use for a month after laying.

29. This will consist of flags of cement concrete moulded separately and thoroughly seasoned, laid on lime concrete over rammed earth as specified for stone flagged flooring. The flags will be moulded as specified under moulded reinforced concrete. A convenient size for the flags is $2' \times 1\frac{1}{2}' \times 1\frac{1}{2}''$. It is essential that the lime concrete foundation should be carefully laid to a true surface so that the slabs may be thoroughly bedded on a thin and even layer of mortar. Moulded cement concrete flag floor.

30. The proportions of cement, sand and aggregate should be decided by experiment, but generally the same specification as for cement concrete floors laid *in situ* may be adopted. The slabs may either be of the same composition all through, or richer in cement in the top layers.

31. Will be laid on lime concrete and rammed earth as specified in paragraph 1. Asphalt floors.

32. Asphalt is usually imported in blocks, known as "mastic," in which the natural asphalt has been mixed with

Asphalt floors—(contd.). sand and bitumen. Val-de-Travers and Seyssel's Asphalt are the best known brands.

33. The following proportion will be used:—

Asphalt (mastic)	32 parts.
Bitumen	1 part.
	33

Coarse sharp sand or fine grit, 25 to 40 per cent. of mastic by weight.

34. The sand or grit must be quite free from dust, clean and dry. It should pass through a sieve of 12 meshes but not through one of 18 meshes to the lineal inch.

35. To mix the asphalt, first lay in the bottom of a caldron about $\frac{1}{4}$ of the bitumen to be used and heat over a wood fire. When this is dissolved, fill the caldron one third full with pieces of mastic weighing not more than 5 lbs. each. As the mastic softens and melts it must be well stirred and more pieces added, until the caldron is nearly full, adding $\frac{1}{2}$ of the bitumen gradually. When the whole is well melted and thoroughly stirred, the sand or grit will be added gradually and the whole stirred until the grit is well incorporated with the mastic: the rest of the bitumen ($\frac{1}{4}$) will then be added. The mixture is ready for use when small jets of steam are being given off and when it will fall freely from the stirrer. None of the composition should adhere to a clean cold iron rod when dipped into it.

36. Strict supervision is required in mixing to prevent too large a proportion of the bitumen being added. Workmen are tempted to do this as the asphalt when so mixed is laid with greater ease than when the proper proportions are used. In hot climates the smallest possible quantity of bitumen which will enable the men to work the material will be added.

37. When the preparation is ready for use, the boiling mixture is to be taken from the caldron with an iron ladle and laid on in rectangles $3' \times 2'$ between wooden gauges, and spread evenly with a hot trowel to the requisite thickness. After one piece is spread, the surface is to be sprinkled with clean sand and rubbed smooth with a hard wood rubber. The gauges are then to be removed and the process continued.

38. Before a fresh piece of asphalt is spread, the edge of the spread asphalt is to be melted by passing a red hot iron over it, to make the connection between the two pieces perfect. Should there be a defect in any point, live charcoal should be placed on the part to soften the asphalt, and if necessary fresh

asphalt added, and the part rubbed smooth with a hot trowel or hard wood rubber. Asphalt floors—(contd.).

39. A ton of pure Val-de-Travers' asphalt with 30 per cent. of fine grit will cover the following areas in superficial yards—$\frac{1}{2}''$ thick, 40 yards; $\frac{3}{4}''$ thick, 30 yards; $1''$ thick, 20 yards; $1\frac{1}{4}''$ thick, 17 yards; $1\frac{1}{2}''$ thick, 15 yards. Work thicker than $1''$ must be laid in two coats, the first coat being allowed to set before the second is added. When two coats are required, each coat should be laid in strips 3 ft. wide, the second coat breaking joint with the first.

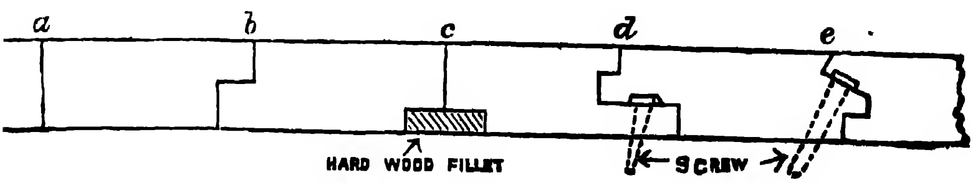
40. The floor boards will rest on joists usually 15 inches apart, which in the case of ground floors will be fixed on dwarf walls of masonry or on pillars on a foundation of $3''$ lime concrete on rammed earth. Free ventilation under the floor must be provided. Wood floors.

41. The floor boards will be of teak, or as otherwise specified, well seasoned, and free from knots or shakes and other imperfections. They will usually be from $1\frac{1}{4}''$ to $1\frac{1}{2}''$ thick, from $4''$ to $6''$ wide, and $6'$ to $12'$ long..

42. The boards will be dressed and planed square and true, with the sides and ends parallel. They will be laid parallel to the long walls of room. The ends will always rest on a joist, and will break joint.

43. Their edges will be jointed as specified in one of the following ways:—

(*a*) shot, (*b*) rebated, (*c*) rebated and filleted, or (*d*), (*e*) secret joints may be given.



44. Screws or nails, as specified, will be given, two at each end, and one at every intermediate joist alternately on opposite sides of the plank.

The planks are to be forced together with a carpenter's cramps or wedges. The cramp will not be removed until the screws or nails have been fixed.

45. After it has been laid the floor will be planed, and made perfectly true and smooth. For high class work nail holes will be filled with "Beaumontage" (see paragraph 46); or round

Wood floors —(contd.). wood plugs cut plankwise may be used over screws as in ships' decks. But usually the best plan for a first class floor is to adopt joint *d* or *e* (see paragraph 43).

Beaumontage. 46. "Beaumontage" or stopping out wax is an exceedingly useful preparation for concealing all defects in floors and woodwork generally. It can be made as follows:—Put a cupful of common shellac in an iron pot, add a teaspoonful of powdered resin, a piece of beeswax the size of half a walnut, and a teaspoonful of powdered lemon chrome or other colouring matter. Heat until the whole is melted, and stir with a stick to mix properly. The mixture can be made into sticks by rolling between boards while still plastic.

It can be used either in sticks, in which case it is applied with the aid of a hot iron as if it were solder, or it may be kept only just melted in a ladle and applied liquid with a hot spoon. In either case, except where the defects have well defined edges, it is advisable to make a few holes with a bradawl to assist in holding the stopping in place. Too much heat in melting will spoil the wax. When quite hard, clean off smooth with a sharp chisel or plane, and finish with glass paper. The wax will not take stains so it must be coloured to suit the finished work.

Earthen floors. 47. The earth used must be a loam or clay, sandy soil or ordinary mould being unsuitable. If the earth is fresh and damp no water will be used; otherwise a little water is to be sprinkled on with the hand. The less water used, the better will the floor be.

The earth will be thoroughly consolidated in 6″ layers until very little mark can be made on it with the heel of a boot. Gravel or moorum will be consolidated in the same way but water should be freely used.

48. In the case of renewals the whole of the old earth will be dug up and removed before any new earth is put down.

Devonshire Barn floor 49. A better type of floor is made by finishing with a 3 to 6 inch layer of earth mixed with lime as follows:—

The clay or other suitable soil will be finely powdered and mixed with lime in the proportion of 5 lbs. lime to 1 cubic foot of earth.

Water will be added in sufficient quantity to make a thick paste. The mixture will be laid to the required depth and beaten. It will be kept moist until the lime has set. This class of floor succeeds only with certain natures of soil, the suitability of which must be determined by experiment.

50. Stone and concrete floors can be prevented from becoming dusty by well rubbing in a mixture of unboiled linseed oil and beeswax, after the floor has thoroughly set, but before it is taken into use. **Prevention of dust.**

Woodwork.

1. The timber will be of teak, sal, deodar, kail or other sound wood locally procurable as specified. **General.**

It must be thoroughly seasoned, free from sapwood, shakes, cracks, large knots, or serious defects of any kind.

2. The framing or timbers will be dressed and planed to the full dimensions shown on the drawings. Unseen timber will not be wrought.

3. All mortice and tenon joints must fit fully and truly, without wedging or filling. Joints should be as simple as possible, and the bearing surface exposed to view, if possible, to ensure correct fit and good workmanship. This does not apply to high class doors and furniture, in which the end of the tenon should not show. Framed joints will always be coated with white lead before the frames are put together. Joints of planks in battened doors will not be coated with glue or white lead. **Joints.**

4. In constructing trusses a full sized drawing of the truss is first to be made on a level platform, from which templates of all tenons, mortises and scarfs, etc., are to be made as a guide to ensure all the trusses being of the same size. **Trusses.**

5. No woodwork is to be placed in position in a building, or painted until passed by an officer. A steel hammer with R cut on one side and ↑ on the other is useful for marking timber that has been rejected or passed. **Passing timber.**

6. Timber buried in the ground should be charred and well coated with solignum or tarred. Woodwork exposed to the weather should be painted or treated with solignum, if the wood is seasoned, otherwise it should be allowed to remain until seasoned, as coating it will do more harm than good by confining the natural juices of the wood, and thus hasten its decay. **Painting, etc.**

7. The ends of all beams, etc., which are to be embedded in walls, and the sides of timbers which are to abut against walls are to be treated with solignum.

8. Where the end of a beam or any woodwork is buried in masonry or brickwork, an air space of ¼ inch is to be left at the end, sides and top. No woodwork of any kind will be laid within 2 ft. of a fireplace or flue.

Painting, etc.—(contd.)

9. The exposed edges of beams, purlins, and rafters, are best finished with a small bead for the sake of appearance.

Fixing.

10. The contract rates will include all lifting and fixing in position of timber, with the cost of all necessary scaffolding, ladders, tackle, nails, spikes, etc., that may be required for the proper execution of the work; also the cost of the fitting of all iron work.

11. All carpenter's work in position will be paid for by net measurements, no allowance being made for wastage nor for dimensions supplied beyond those ordered.

Doors and Windows.

General.

1. Drawings of several types of doors are given in Plates XXXI—XXXIII.

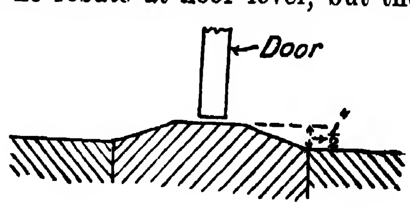
Doors will be battened, framed and battened, panelled, or panelled and glazed as specified.

Doors for outhouses or unimportant buildings may be constructed of corrugated or plain G. I sheeting.

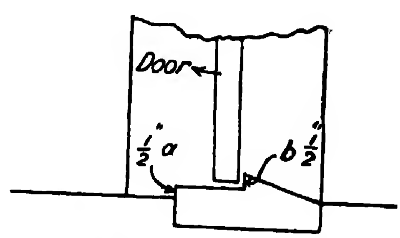
2. Internal doors should not be less than 2′ 9″ wide by 6′ 6″ high. Doors of greater width than $3\frac{1}{2}$ feet will generally be made in two leaves.

3. Chowkats will be of wood, reinforced concrete or angle steel, as specified. For ordinary doors and windows the chowkats should not usually exceed 4″ × 3″ in section, and may be even lighter in certain cases.

Single hung doors require no rebate at floor level, but the sill may be raised half an inch or so, as in the sketch, to allow of the door clearing matting or carpets, while excluding draughts.



A suitable arrangement for double hung doors is shown in the sketch opposite.



(a″ may be omitted and b″ made 1″)

4. Clerestory windows should be pivotted and may be so balanced as to close by gravity: one rope can then generally be dispensed with.

Farming.

5. Joinery will be of the best wood obtainable of the kind specified. The planks should be cut from the log some months before being used.

6. The styles, rails, panels, sash bars, etc., are to be accurately cut and fitted to the dimensions given in the drawings. The width of rails for doors will not be less than $4\frac{1}{2}''$, and for windows up to $3'$ wide not less than $3\frac{1}{2}''$. Where mortice locks are used, the lock rail will be not less than $8''$ wide, to allow room for the lock between the tenons.

7. The tenons of all rails are to pass right through the style with a thickness of not less than $\frac{1}{4}$ of the style. This does not apply to really high class doors (see Woodwork, paragraph 3).

8. Before being put together all joints will receive a priming coat.

9. Sash bars will usually not be less than $1\frac{1}{4}''$ wide, the rebates therein to be $\frac{3}{8}''$ wide and $\frac{3}{4}''$ deep. Sash bars are to be properly jointed and pinned to the frames, halved into each other, glued with English glue, and no nails or screws used.

10. All fittings such as handles, bolts, etc., must be strong and well secured. Stout ring handles are to be preferred to knob handles, which latter should be cast or filled in solid, to prevent their being indented. **Fitting.**

11. All doors will be provided with three iron butt hinges of suitable size to each leaf unless otherwise specified. For wire gauze doors spring hinges are generally required, but in some cases self-closing is better obtained by means of a weighted cord and pulley. **Hinges.**

12. Iron rim locks will be used for all ordinary barrack purposes where locks are required, but in barrack rooms a hasp and staple carrying a padlock is generally sufficient. The length of locks should be specified in inches, also whether right or left hand are required, a right handed lock being one which is fixed on the right hand side of a door. In fortified places, arsenals, or Government factories, the locks should be in series on the master key principle, with duplicate keys and labels. **Locks.**

13. Keys should have solid bows; ring keys with an open bow, should be filled in with brass before issue. The bow should be engraved or stamped with M. W. on one side, and with the number of building or room on the other. **Keys.**

14. Each door or window will usually be furnished with one or more best iron tower bolts per flap. Their length, which must be specified in inches, should not usually exceed 12 inches, but the upper bolt must be of such a length as to be within easy reach of a man standing on the floor. **Tower bolts, etc.**

The staple must always be fixed with two screws on each side. Screws used for securing bolts and exposed fittings must

Tower bolts, etc.—(contd.). be either round-headed or else must be countersunk with their heads flush in the fitting.

15. For out-offices, and where otherwise specified, the Norfolk thumb latch, large, middling, or small, will be used.

In loose boxes of stables, horse infirmaries and localities in which projections are inadmissible, flush latches will be used.

Glazing.

16. The glass will be sheet glass, free from flaws, specks or bubbles. Standard sizes of panes should be used where possible.

For officers quarters 21 oz. seconds, and for other buildings 15 oz. thirds will be used unless otherwise specified.

17. The distance between rebates should be slightly larger than the size of panes, since the glass must nowhere touch the woodwork of the frame, otherwise any jar to the frame would be liable to crack it.

18. The whole sash bar, but especially the rebate which is to receive the putty, will first be well primed, to prevent the wood drawing the oil out of the putty.

19. The back putty is then drawn along the inner edge of the rebates for the glass to bed on: the pane is put in position, well bedded all round on the back putty, and secured in the rebates by four or more brads and by front putty, sloping from the inner to the outer edge of the rebate. Care should be taken to keep the putty a little within the inner edge of the rebate, so that none of it may show through the glass from the inside. Putty should always be put on with a proper putty knife.

20. Both the front and back putty (where exposed) should then be covered with a coat of paint, to protect it from the air, or it will shrink and get loose as the oil dries out of it.

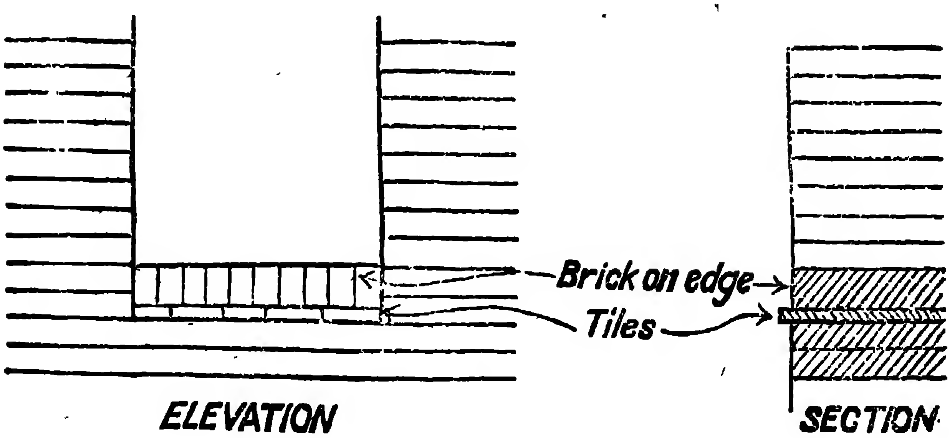
21. In reputtying panes of glass, all the old putty is to be carefully removed and replaced by new. The rebates are to be thoroughly cleaned and moistened with raw linseed oil before being reputtied.

22. The glass both in new work and in replacing broken panes is to be thoroughly cleaned before the work is accepted as finished.

Putty.

23. Putty will be made as follows. Take 1 seer finely powdered whiting, 1 chittack white lead (dry), 6 chittacks raw linseed oil, 2½ tolas litharge, mix well together and beat with a wooden mallet until thoroughly incorporated. If the putty becomes hard it can be restored by heating it and working it up again while hot.

24. For window sills, parapet copings, etc., a general use of this type of detail is recommended:— Putty—(contd.).



viz., a brick on edge coping surmounting a tile "creasing," the whole occupying exactly the height of two ordinary courses of brick-work. The coping to be set flush with the general wall face and the creasing to have not more than one inch projection.

For the creasing, tiles ½ inch thick can be used in two layers breaking joint or a single course of tiles about 1⅛ inch thickness.

Ironwork.

1. All wrought iron or steel articles are to be manufactured from iron equal in quality to best Staffordshire, or from mild steel, and are to be approved by an officer before being fixed. They are to be forged clean from the anvil, and neatly, soundly and properly finished. For any special work a special specification must always be given. General.

2. All edges must be filed square when directed. All bolt and rivet holes may be punched, unless drilling is specified.

3. All bolts and nuts must be to Whitworth standard, both as regards threads and sizes of heads and nuts. The heads and nuts are to be hexagonal unless otherwise specified. All bolts must be screwed for a length of three diameters. The screws of all bolts should show a full thread above the nut when the latter has been screwed up tight, any length beyond this being cut off as required. Machine made bolts and nuts should usually be specified. Bolts and nuts.

4. All rivets must fit fully and truly; the holes made for them must be of the sizes and in the positions shown on the drawings; and if the rivets shake at all from the blow of a hammer they must be cut out and replaced. To test rivets Rivets.

Rivets—(*contd.*) place a finger on the rivet and tap with a hammer on the opposite side.

Castings. 5. All castings must be clean and sound and entirely free from airholes or defects of any kind. They must not be painted till passed by an officer.

6. Straps, bolts, and other ironwork will be thoroughly cleaned from rust, and dipped in boiling linseed oil before being fixed in the work. Unseen ironwork such as hold-fasts, trusses hidden by ceilings, etc., will be tarred.

7. All ironwork will be tendered for and paid for by the cwt. and not by the maund.

Painting.

Woodwork. 1. All exposed woodwork will be painted, unless otherwise directed and interior woodwork will be painted, oiled or varnished.

All woodwork must be properly seasoned and free from moisture in its pores before the application of paint, oil or varnish, or dry rot may be caused. Painting should as far as possible only be carried out in dry weather.

2. Painting is best done departmentally or by piece work, and in all cases it is essential that all materials should be supplied and mixed departmentally, and precautions taken to prevent the addition of cheap bazar oils to the paint. The preservative quality of paint depends on the toughness and impermeability of the skin formed by the boiled linseed oil in combination with pigments. Everything added to this, such as driers, turpentine, inferior pigments, etc., tends to weaken the paint and reduce its life. It is therefore important that none but the best boiled linseed oil and the soundest pigments should be used and that no more driers, turpentine, etc., be added than is found to be absolutely necessary.

Materials. 3. The paint used will be the best Silicate paint obtained, through the India Office, or Shalimar paints obtained from the Shalimar Paint and Varnish Company, Calcutta. The paint should be ordered ground in oil. Shalimar Paint may be obtained ready mixed.

4. The best quality of boiled linseed oil, known as pale boiled oil, will be used. It can be obtained of local manufacture and good quality from Ghorepore and elsewhere.

5. A proportion of raw linseed oil will be used for white paint and may be used for other light colours in interior work.

6. The proportions in which the paint should be mixed depends on the nature of the pigments, climate and other considerations. The following is given as a guide, but the correct mixture should be determined by experiment in each station:— Mixing.

—	1st coat.	2nd coat.
Silicate Paint	7 lbs. .	7 lbs.
Boiled linseed oil	$3\frac{1}{3}$ pints . .	$4\frac{1}{2}$ pints.
Driers	1 lb. . .	1 lb.
Turpentine	$1\frac{2}{3}$ pints.	

The oil and turpentine will be first mixed, and added to the ground pigment, mixing well until the paint flows freely from the brush. The driers will be added just before using. In finishing coats, if a specially good surface is required, $\frac{1}{3}$rd to $\frac{1}{4}$th of the thinning may be of copal varnish instead of oil.

7. Before applying the paint the woodwork must be thoroughly cleaned, all projections removed, knots or holes covered or filled in with a preparation of red lead and glue size laid on hot, called knotting. The knots in resinous woods such as deodar should be painted over with hot lime. After 24 hours the lime is scraped off and the knots painted with red and white lead and linseed oil. Preparation of woodwork.

8. This will be of red lead, or of red and white lead mixed in boiled linseed oil only (7lbs. red lead to 4 pints boiled linseed oil). When dry, all cracks or holes are to be filled up with putty and the whole surface rubbed down with pumice stone or sandpaper and well dusted. Priming coat.

9. The second coat will be of any desired colour, mixed as directed, and will be laid on in the same manner as the priming coat. When dry the surface will be rubbed down with pumice or glass paper. Second coat.

10. The third coat will be applied in the same manner as the preceding ones, greater care being necessary to prevent brush marks being visible on its completion. It should be of a slightly different tint to the previous coat. Third coat.

11. The paint will be applied with brushes and spread as evenly and as smoothly as possible. To effect this, as soon as the whole or a convenient quantity is covered, the brush should be passed over it in a direction contrary to that in which it is finally to be laid off; this is called crossing. After crossing,

Third coat—(*contd.*). it should be laid off softly and carefully in a direction contrary to the crossing, but with the grain of the wood, taking care that none of the crossed brush marks be left visible.

The criterion of good workmanship is that the paint be laid evenly, and the brush marks be not observed. In laying off the brush should be laid into that portion of the work already done, so that the joining may not be perceived.

12. Every coat should be perfectly dry and passed by the Officer in charge of the work, and all dust carefully removed, before the succeeding one is laid over it.

13. The paint must not be allowed to settle in the cans; to prevent this each painter will have in his tin can a small smooth stick, with which he must be made to stir up the paint occasionally. If it has to be laid on one side for a time in an open vessel, it should be covered with water to prevent oxidisation and drying.

Repainting old work. 14. The old paint will be carefully examined. If firm and sound, it will be well rubbed down with pumice stone, greasy places being rubbed with turpentine. It will then be given one renewal coat.

If decayed, or unsightly from the accumulation of many old coats, it will be entirely removed and two or more new coats, with or without a fresh priming coat, as examination indicates, will be given as for new work.

The old paint will be burnt off with air pressure flare lamps, or removed with Shalimar or other suitable Paint Remover.

Varnishing. 15. The surface of the wood having been thoroughly cleaned, stopped and sandpapered over, one or more coats of glue size will be given. This will be made of selected clear glue of consistency to run freely in a brush when hot. When dry, a coat of copal, oak or wainscotting varnish will be given, followed by a second coat if necessary.

The hard drying copal or oak varnishes are suitable for interiors and furniture and the heavier oil varieties of copal varnish where protection from the weather is sought.

Oiling. 16. Earth oiling consists in the application of crude earth oil or petroleum, warmed till it flows freely from a brush, to the surface of the woodwork.

In the case of Shingle roofs, a proportion of oxide of iron should be added to the oil to colour the shingle red.

Where employed as a preservative on teak houses, as in Burma, an annual coat is required both on roofs and exposed walls. In India a coat applied every third year or so on un-

painted timber, as in verandah roofs, etc., preserves the work to some extent from insect attacks and the weather, whilst the woodwork assumes a neat varnished appearance in time. Oiling—(*contd.*).

17. The plaster must be carefully laid, and its surface free from air bubbles or flaws caused by the blowing of the lime. **Painting plaster.**

It is essential that both the plaster and the wall be perfectly dry before the painting is commenced.

18. The plaster will either be primed with glue size to prevent absorption, and then four coats of ordinary paint applied, or it may be primed with two or three coats of boiled linseed oil, which, when dry, is covered with a thin coat of weak size tinged with red lead to stop all absorption and give the work a uniform appearance; it is then finished off with two coats of oil paint.

19. All ironwork should have the surface protected from rust before the work leaves the Assistant Commanding Royal Engineer's workshop, for when once the metal begins to oxidise the process is most difficult to arrest. Paint or other protecting coat will peel off if applied to a surface containing any particles of rust. Whenever possible the metal, while still black hot, will be immersed in a trough of the best boiled linseed oil. **Painting ironwork.**

20. If the metal has been allowed to grow cold before coating, it must be thoroughly cleaned from rust and dirt by scraping or brushing with steel wire brushes and kerosine oil, and, when dry, coated with best boiled linseed oil.

21. Ironwork such as door holdfasts, cramps, straps, etc., will be coal-tarred, the tar being mixed in the proportion of 4 parts tar to 1 part kerosine oil heated together and applied hot.

22. If it is considered desirable to paint the ironwork, red lead paint should be used for important structural iron or steel work. This will be mixed in the following proportions:—

Red lead	100 lbs. (see below)
White zinc	20 ,,
Raw linseed oil	5 gallons.
Turpentine	3¾ pints.

For 3 coat work, 60 lbs. red lead for the first coat, 80 lbs. for the second and 100 lbs. for the third to be used.

23. For unimportant ironwork, or for roofs, red oxide of iron paint will be used. This is obtainable of local manufacture from Olphert's Paint Works, Katni. In mixing it a small quantity of turpentine is necessary.

Tile Burning.

Construction of kiln.

1. The construction of the Sialkot pattern kiln for burning tiles is shown in plate II.

Loading.

2. On the brick flooring is packed a layer of semi-hexagonal tiles on end, placed one with its neck, the other with its broad end downwards alternately, and the spaces at the sides of the kiln are packed with semi-cylindrical tiles.

The succeeding four layers are of flat tiles on edge, placed in squares of eight, alternate squares at right angles to each other. Odd spaces are filled with semi-cylindrical tiles.

Over the 5th layer a course of kutcha bricks laid flat are placed, with small chimneys of sheet iron 15″ long by 4″ diameter.

Over the bricks a layer of charcoal 3″ deep; so as to burn the upper portion of the bricks. Success depends largely on careful loading.

Firing.

3. Sufficient fuel must be at hand to burn the kiln completely, for this from 150 to 200 maunds of wood are required. This should be in pieces 3″ to 6″ diameter not exceeding 5′ in length.

Fires are kindled in all 7 fire holes simultaneously and are kept at the mouths of the kiln for 16 hours, and are gradually fed till the tiles and the interior of the kiln are thoroughly dried. This is indicated by the smoke from the kiln turning from a dark to a very light colour.

The fires are then pushed to the far end of the kiln, and a brisk fire kept up for three hours. During this stage the charcoal at the top catches fire, and as it does so it is stopped down with damp clay. The fires are now gradually slowed down for 6 hours.

Then another brisk firing for 3 hours, this sequence being followed all through the firing operations. The total length of time taken in firing will be 72 hours.

After the firing is completed and the kiln left to cool, the feed holes should be blocked up with bricks, and the chimneys closed.

4. For use with coal fuel fire bars are required. These may be of flat steel bars, $1\frac{1}{2}'' \times \frac{1}{2}''$, supported on steel angles.

The amount of coal required is about 60 cwt.

5. This type of kiln has been used successfully at Bareilly. The tiles there are stacked in 7 tiers; the brick flooring is omitted, and the tiles stacked directly on the fire. The flat tiles are also stacked in rows and not as described above.

Roofing.

1. The tiles will be thoroughly well burnt Mangalore tiles, sound, of a uniform colour, giving a clear ring when struck, and free from twists or any other defect. **Mangalore Tiling.**

2. They will be laid square and properly fitting, with the catches resting fully on battens, nailed to the upper surface of the rafters and at right angles to their direction. Care must be taken that each course is laid perfectly parallel to the rafters.

The spacing of the battens varies for different makes of tiles. For Basel Mission tiles the spacing is $12\frac{1}{2}''$; for Cawnpore pattern-tiles $13\frac{3}{4}''$ centre to centre.

The lowest or eaves batten will be of extra depth ($\frac{3}{4}''$) to make the slope even and continuous from ridge to eaves.

3. The ridge and hip tiles will be set in lime mortar; the eaves tiles will be screwed to the eaves batten except when bedded in masonry. Tiles at gable ends must be similarly fixed to the battens.

Special ventilating tiles are obtainable for use either on slopes or in ridges.

4. Single Mangalore tiling is not absolutely water tight in very heavy or driving rain. Where such is anticipated, the tiles may be laid on Corrugated Iron as specified in paragraph 18, etc., or a ceiling may be given. Special ceiling tiles for use with Mangalore tiles are obtainable from the Basel Mission and elsewhere.

5. The tiling will be single or double as specified. **Allahabad Tiling.**

6. Double tiling will consist of a layer of flat tiles laid on battens. The side joints of every two adjacent flat tiles will be covered by semi-hexagonal tiles. Over these semi-hexagonal tiles will be laid another layer of flat tiles, the adjacent edges of every two of the latter being covered by a semi-cylindrical tile.

7. Single tiling will consist of a layer of flat tiles as for the lower layer of double tiling, the edges of every two adjacent tiles being covered with a semi-cylindrical tile.

8. All tiles must be thoroughly well burnt, sound, of uniform colour, free from twists or other defects. They must be of a dark red colour and ring clearly when struck.

9. All tiles must fit closely and well, the moulded niche at the lower end of each flat tile fitting completely into the head of the tile next below it, and the buttons at the upper end must have a firm hold on the wooden battens placed at $1'$ intervals to receive them.

Allahabad Tiling—(contd.).

Each semi-hexagonal must fit exactly in its position, both on the flat tiles under it, and also into the bed specially formed in the upper part of the next semi-hexagonal to receive it.

10. The upper layer of flat tiles must be exactly the thickness of the semi-hexagonals. They will then exactly overlap each other by 3 inches, and yet fit in the position made for them on the semi-hexagonal tiles, the lower buttons taking the lugs moulded on the sides of the semi-hexagons to receive them.

11. Over this upper layer of flat tiles and covering the two adjacent edges of every row will be laid a row of semi-cylindrical tiles, which again must fit exactly on the flat tiles, the shoulder of the niche cut-out of each coming in close contract with the lower edge of the flat tile under it, and the buttons towards the lower end will lie exactly on the upper edge of the semi-cylindrical tile next beneath it. The three lowest tiles in each layer will be set in lime mortar.

12. Specially manufactured tiles will be used for ridges and hips, which will be set in lime mortar. Tiles to be set in lime mortar will be soaked in water for 4 hours before laying, and kept well watered for five days after laying. Special ventilating ridge tiles are also often used.

13. The ends of each row of semi-hexagonal and semi-cylindrical tiles will be filled up with lime mortar and in the case of double tiling the space between the two rows of flat tiles will also be so filled. Special eaves tiles with closed ends may also be specially manufactured.

14. A wood rasp may be used for making the tiles fit closely; but any tile which cannot be made to fit without injury from rasping must be rejected.

When the roof is completed all the lines of the tiling must be perfectly even and straight. This will best be observed by noticing the diagonal lines made on the roof by the ends of the semi-cylindrical tiles.

15. Full details of the manufacture of all these tiles will be found in "Roorkee Professional Papers," Volume III, 2nd Series, page 146, by Major G. P. deP. Falconnet, R.E.

Country Tiling.

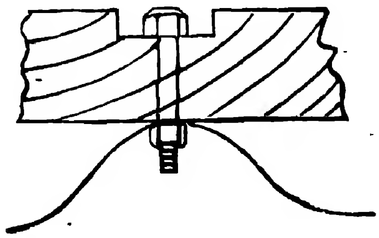
16. Tiles will be the best wheel tiles, well burnt from good tempered clay, free from cracks and flaws; they should average 10″ long by 4″ broad at one end tapering to 3″ at the other.

17. They will be laid single or double as specified by the Officer in charge at right angles to the ridge, fitting closely into one another. A 4″ lap will be given, and great care is to be taken that the upper tiles are tightly locked.

Ridges, eaves and hips will be set in lime mortar.

18. The corrugated iron will be laid as specified for corrugated galvanised iron roofing. **Mangalore Tiles over C. G. I. roofing.**

19. Battens will be secured to the corrugated iron by means of 2″ galvanised bolts spaced at about 28″ centres, the heads being countersunk, as in the sketch, to admit of the tiles resting on the battens. Galvanised iron screws may also be used.



20. The tiles are laid on the battens as specified for Mangalore tiling.

21. Country tiles will be laid directly on the corrugated iron, a batten being fixed at the eaves to prevent the tiles slipping. **Country tiles over corrugated iron.**

22. The corrugated iron will be of the gauge specified. The surface of the sheets must be clean and bright and free from rust. Any sheets showing a white powdery deposit should be rejected. **Corrugated galvanised iron roofing.**

23. The sheets will be laid on horizontal purlins. There should usually be one at each end and one in the middle of each sheet.

24. Each sheet will be laid with a lap of 6 inches in its length. The side laps will extend over two corrugations, and will be turned away from the rainy quarter.

25. The sheets may either be rivetted, or jointed by means of Price's limpet washers.

26. When the sheets are to be rivetted, they should be made up on the ground in sets, generally three sheets in length, and three or four in breadth.

27. The sheets should be placed on trestles about 2′ high, so as to allow men to work underneath.

The rivet holes will be drilled or punched from below upwards so that the arris may be at the top.

All holes will be in the ridges and never in the gutters of the corrugations.

The tools must be very sharp so that there may be no tearing of the sheet, and the holes must be clean punched out.

Each sheet will be rivetted at the corners and at least once in its breadth, and rivets will be spaced evenly at from 1 to 2 feet intervals along its length. At the corners, where the rivets have to go through four sheets, it is better to drill the holes.

28. The rivets will be of galvanised iron, and will be passed through from below, and held up firmly by a bolster resting on

Corrugated galvanised iron roofing —(*contd.*).

a block of wood placed on the ground. A leaden washer fitting tight to the shank of the rivet and extending $\frac{1}{2}$ inch all round beyond the edge of the hole will be put on, and the rivet head will be made over it with a light hammer, and finished off with a capping tool. Great care must be taken that the sheet is well supported underneath, and that no indentation be made on the upper surface of the corrugation.

29. The sets will then be hoisted on to the roof and will there be rivetted together in the manner already described.

30. The sheets will be secured to the timbering by means of galvanised screws, clips or hooked bolts passing through the sheets and round the timber. Each sheet will be held down to the purlins by two or more screws or $\frac{3}{8}''$ bolts. Bolts or screws will always be placed at corners where four sheets overlap each other.

Excellent rounded iron clips with little bolts and washers are now provided by all makers for fixing the sheeting to steel purlins, and their use is recommended. All clips, bolts, or hooks must be galvanised.

31. The bolt holes must be slightly larger than the diameter of the bolt, so as to allow of contraction and expansion of the mass of the roof covering. These holes will be covered by a limpet or leaden washer fitting tight to the shank of the bolt, and extending $\frac{1}{2}$ an inch all round beyond the hole.

32. All rivets, bolts, etc., will be set in white lead.

33. Limpet washers make good and impervious joints and skilled labour is not required as in the case of rivetting. These washers when screwed down adapt themselves exactly to the curve of the corrugation and need not be set in white lead. Patent bolts to suit the peculiar shape of the washers are made and should be used with them.

34. The ridges and hips will be covered by plain galvanised iron sheeting, which will be rivetted or fastened with limpet washers to the corrugated iron. This sheeting will be laid in lengths with an overlap of at least 9 inches, the joints being set in white lead.

The sheeting should not be built into the gable end parapet walls. The long edge should be well bent up, and a drip course, built into the parapet, should cover the end by at least 3 inches.

35. When galvanised iron is laid on deodar framing, steps must be taken to prevent the deodar touching the galvanised iron, otherwise the galvanising will be destroyed by chemical action.

36. In windy or exposed situations it is necessary to fasten down the sheets at the eaves and gables by continuous lengths of steel flat about $2'' \times \frac{1}{4}''$ bolted down to the masonry at about $4'$ intervals. These bolts should not be less than $1\frac{1}{2}$ feet in length, with $6''$ square plates embedded in the masonry. **Corrugated galvanised iron roofing—(contd.).**

37. The roof covering will consist of plain or corrugated galvanised iron sheets, 24 S. W. G. or as may be specified. **Naini Tal pattern roofing.**

38. The sheeting will be laid on planking of chir, deodar or other wood of the thickness specified. The planks in barrack rooms will touch each other laterally, and in subsidiary buildings be spaced at intervals, equal to their breadth. The planking will be secured to the rafters by 3 inch screws, spaced as may be directed.

If corrugated iron sheeting be used it may be laid on purlins spaced as directed in paragraph 23.

39. The battens B (see Plate XX, Fig. 2), $2'' \times 1\frac{1}{2}''$, will be secured to the planks by screws $3''$ long and 3 feet apart, driven from below. The ends of the battens at the eaves will be rivetted through to the planking with an iron rivet $\frac{3}{4}''$ diameter, with washers $1\frac{1}{2}'' \times 1\frac{1}{2}'' \times \frac{1}{8}''$ at each end of the rivet (see C, Plate XXI). Planking battens and fillets will be tarred before fixing.

40. The sheets will have their longitudinal edges curved by first hammering them with a wooden mallet, with a curved head, on a wooden platform; the other side of the sheet being gradually elevated, until the edge under treatment has assumed the form required approximately.

The edge is then finished off by being hammered with the same mallet round a wooden bar of the required shape.

The sheet thus prepared will be placed on the roof, and be secured to the planking at its upper edge by one $1\frac{1}{4}''$ screw (see F, Plate XXI) placed $1\frac{1}{2}''$ from the upper edge of the sheet, and half way between the battens.

The sheets are held down at their edges by three iron clips $3\frac{7}{8}'' \times \frac{3}{4}'' \times \frac{1}{4}''$ (see E. Plate XXI) countersunk into the battens. The clips are made from the iron bands, which are used to bind the bundles of iron for transport, and will be screwed down to the battens with $1\frac{1}{2}''$ screws, $\frac{1}{2}$ inch apart in the clear. The sheets will be laid with a $6''$ overlap.

41. The rolls or covering strips (see A, Plate XXI) will be of plain galvanised sheet iron of 22 S. W. G. The strips will be hammered round a bar of proper shape with the wooden mallet mentioned above, and when nearly of the shape required, an iron ring of proper shape will be placed over the roll and

Naini Tal pattern roofing—(*contd.*).

wooden bar at one end and hammered down the bar to the other end, thus forcing the roll to assume the exact shape of the bar. The rolls will then be slipped on to the battens, and each secured by one $1\frac{1}{2}''$ screw (see H, Plate XXI), placed $1\frac{1}{2}''$ from the upper edge of the roll.

42. The ridge will then be covered in with specially shaped ridging or plain galvanised iron sheeting, of 18 S. W. G. These sheets will be 2 feet wide, and will be curved along their upper edges in the manner described in paragraph 40. They will be laid on the battens supporting the rolls, or on planking screwed to the battens, with a 9 inch overlap (see G, Plate XXI), the joint or overlap being set in white lead.

To secure these sheets, clips, KK, $13'' \times 1'' \times \frac{3}{16}''$, will first be screwed down to the battens (through the planking) with two $2''$ screws (Plate XX, Figs. 1-2). The lower edge of each sheet will then be inserted in the clips, and the upper curved edge of the sheet brought against the ridge board, where it will be secured in the manner described in paragraph 40 (Plate XX, Fig. 2), thus leaving neither screws nor rivets exposed. A wooden fillet $1'\ 9'' \times 1\frac{1}{2}'' \times \frac{3}{4}''$ should be inserted under the end of the rolls A to prevent the screws holding down the clips K flattening them out (Plate XX, Fig. 1).

The special shaped ridging, if used, will be fixed at its edge by similar clips as described above, and if considered necessary will be further secured by galvanised iron screws to the ridge plate.

43. The ridge sheets being fixed will be covered by a roll similar to those specified in paragraph 41 running along the whole length of the ridge (Plate XX, Fig. 2).

44. Each sheet and roll at the eaves must be held down by an iron clip (see L and M, Plate XX) screwed to the planking, and passing over the end of the sheet or roll (two clips L should be given to sheets more than 2′ wide). This is to prevent the wind getting between the sheet and the planking, and raising the former up at its lower extremity.

45. All clips and screws used are to be galvanised.

46. The labour of bending sheets and rolls, and the cost of roofing is reduced by using a machine of the type shown in plate XXII.

47. When ungalvanised iron is used, the sheets will be given a coat of tar laid on hot on the underside before being placed in position, and on the completion of the work the roof covering will receive two coats of Olphert's paint, laid on as specified under "Painting," after the surface has been

thoroughly cleaned and all signs of rust removed by scraping and brushing. This must be done in fine dry weather.

Naini Tal pattern roofing—(*concld.*).

Dharmsala pattern roofing.

48. This is a modification of Naini Tal pattern roofing, which has been successfully used in the Dharmsala district. The sheets will be laid on planking in the same manner as for Naini Tal roofing with the following exceptions. The wooden battens B will be omitted, and the sheets will be laid at an interval of $\frac{3}{8}''$. The curved edges of adjacent sheets will be held down by four clips of hoop iron $1\frac{1}{2}'' \times 1'' \times \frac{1}{8}''$, screwed down to the planking with $2''$ screws (see Plate XXI).

49. The covering rolls will be smaller, $4''$ width, and will be slipped over the pair of curved edges, and secured by $3''$ screws at their upper ends.

Rimington pattern roofing.

50. Is a modification of Naini Tal pattern roofing in which the wooden battens (B) are replaced by strips of hoop iron shaped as in Plate XXI.

In other details it is similar to the Naini Tal pattern roofing.

Battman Pattern roofing.

51. This is a modification of the Le Mesurier pattern roofing, which has been successfully used in the Rawalpindi Division.

52. The roof covering will be 24 S. W. G. plain galvanised iron sheets laid on $1''$ planking. The sheets will be bent and laid as shown in Plate XXI. Each sheet will be held down by two $1''$ galvanised screws at the top edge, and three $2\frac{1}{2}''$ galvanised iron screws with limpet washers through the rolls. There will be a wooden fillet $6''$ long, section as in the drawing referred to, under each washer.

Each sheet at the eaves will also be secured by two $1''$ galvanised screws with washers. The sheets will be laid with a $6''$ end to end overlap.

Terraced roofs.

53. The roofing will be supported on jack arches or on tiles or flags laid on steel joists over Rolled Steel beams as may be specified.

54. The lime concrete will be mixed as specified for concrete. The aggregate will be of broken brick made from hard, sound, well burnt or over-burnt bricks broken to $1\frac{1}{2}''$ gauge.

55. The lime concrete will be laid and finished as specified for terraced flooring.

Mud roofing.

56. The roofing will consist of 6 inches of mud laid on tiles as may be specified. The tiles, which are usually $12'' \times 6'' \times 2''$, should be well soaked before being laid in mortar on the battens. The upper and lower surfaces should be carefully pointed, and no earth should be laid on the tiles until they have been inspected by an officer. The mud will be stiff clay, and after being excavated will be spread out to be scorched by the

Mud roofing —(*contd.*). sun. It will then be powdered and stacked in heaps of about 100 cubic feet. Water will be added and the clay well mixed by treading with the feet, until the whole assumes the consistency of stiff mortar.

It will then be laid on the roof and beaten until quite hard. It will be finished off with a coat of mud plaster, and leeped as described in the specification for mud plaster.

Jack arch roofing. 57. The rolled steel beams should be free from rust pits, thoroughly freed from rust by means of wire brushes and kerosine oil, and given at least 3 coats of paint before being laid in position.

58. The centerings may be made on pillars built up from the ground, or may be suspended from the rolled steel beams. In the latter case the cross timbers carrying the centering should be suspended from the outer flanges of the rolled steel beams by means of stout hook bolts of square section, to prevent the beams being displaced by the thrust of the arch due to the centering settling under its load.

As the weight of suspended centerings is not usually included in calculations for the beam, it is desirable that the latter should be propped to prevent cracks in the terracing due to the spring back of the beam when released from its load. The top surfacing of the centering should consist of as impermeable a clay as possible to prevent the mortar running through the joints. The courses of brickwork should be marked out on the surfacing and the curvature checked by means of a template capable of application after completion.

Centerings should not be moved till after consolidation of the concrete terracing.

59. The bricks for the springing course should be cut to template on the ground in sufficient numbers before the commencement of the arch. The remaining bricks are not usually cut to shape, the radial joint divergence being made good with mortar, or specially moulded bricks may be used.

The bricks are generally laid with their bed faces ($9'' \times 4\frac{1}{2}''$) normal to the arch thrust, with the advantage of having less mortar joints under compression, and opposing some bond to the longitudinal crack which sometimes forms along the crown of a faulty arch.

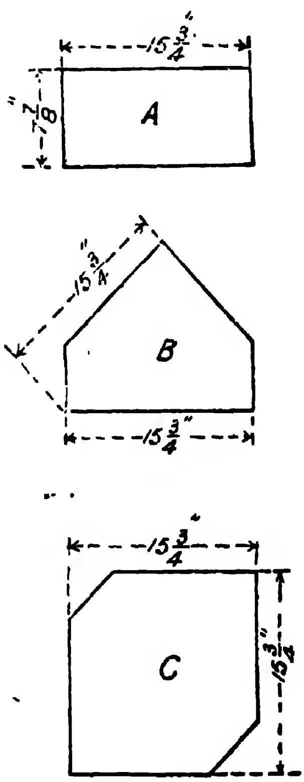
60. In hipped roofs, ribs or groins, consisting of courses of bricks laid on the centering on edge along the lines of intersection of corresponding jack arches, are first formed; and the bricks of the jack arches on each side are butted up against

them at the required angle of incidence. An angle cleat is rivetted on to the lower end of the rolled steel hip beam to take the thrust of the groin. Jack arch roofing—(*contd.*).

61. The rods are placed in the end arches of a given length of roof, or in the larger of two unequal span arches where such spring from the same beam.

Small section tie rods such as $\frac{1}{2}''$ and $\frac{5}{8}''$ diameter distribute the thrust better and do not need any angle iron bearing pieces for stiffening purposes.

The centering should not be allowed to rest on the tie rods.



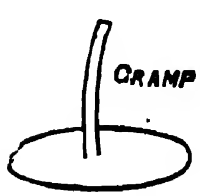
62. The rise of the arch should be about $\frac{1}{8}$ of the span, and the most desirable span is between 4 and 6 feet. Eternit slate roofing.

63. The slates will be laid on battens spaced at $9\frac{1}{2}''$ centre to centre. The lowest or eaves batten will be spaced $7\frac{1}{4}''$ from the next above.

64. In laying the slates, the first row at the eaves will be slates A (see marginal drawings), next of slates B, the remaining rows being of slates C. C is the standard size of slate, out of which either A or B can be cut. They will be laid with an overlap of about $2\frac{3}{4}''$.

65. Slates A and B are fixed with galvanised iron or copper nails, slates C with nails and cramps.

66. The cramps consist of a disc and pin (see marginal sketch). The disc is slipped under the adjacent edges of two slates, and through the corner of the slate above, binding all three together.



67. About 62 slates cover 100 square feet of roof area. The standard size of slate is $15\frac{3}{4}'' \times 15\frac{3}{4}''$, and is made in three colours, grey, red and black.

Flashing, Gutters and Valleys.

General. 1. Gutters or flashing will be of milled lead weighing 6lbs. per square foot, or, where cheapness is of importance, of zinc sheeting 18 S. W. G. or as otherwise specified.

They must be arranged so as to give free play for expansion and contraction in any direction.

2. When the edges of sheeting are turned up, as in gutters, against the side of a chimney shaft or against a wall, the edge is left free and a flashing, secured along the joints of the masonry, is bent down over the up-turned edge of the gutter sheeting, which it should overlap about 4 inches; thus one edge of each piece of sheeting is left free to expand and contract.

3. The upper edge of the flashing will be fixed by being tucked into the joints of the brickwork or masonry, which will be raked out for a depth of about 2″, and wedged in with small plugs of wood. The joints will be finally filled in with mortar.

4. The flashing should be stepped, each step being cut back so as to keep out the weather better.

Gutters. 5. Gutters should have a fall of at least 1 inch in 10 feet.

6. Rain water down pipes will be made of galvanised sheet iron, bent on a cylindrical core and rivetted with a lap of $\frac{5}{8}$″ beyond the rivet heads, or light quality cast iron pipes may be used.

Valleys. 7. Valleys of lead, zinc or galvanised iron sheeting will be not less than 6″ wide at the bottom and turned up under the roofing 21″ on each side.

Ceilings.

Lime plaster and wire netting ceiling. 1. The wire netting should be of ungalvanised wire not more than $\frac{3}{4}$″ mesh: the smaller the mesh the better. When galvanised wire netting is used, the preliminary wash described in paragraph 3 is particularly necessary.

It is ordinarily fixed to rafters or battens not more than 1′ 6″ centre to centre.

2. The roll of wire, usually 3′ in width, is stretched at right angles to the battens or rafters and fixed thereto by means of $1\frac{1}{2}$″ wire nails at intervals of 6″ or less. The nails being driven into the timber for 1″, and the remaining $\frac{1}{2}$″ bent over a strand of the wire and hammered down, care should be taken that the wire is stretched quite tight before nailing; this may easily be effected by inserting a small iron rod into one of the meshes and using it as a lever against one of the battens. The edges

Lime plaster and wire netting ceiling—(contd.).

of separate lengths to be tied together with soft iron wire about 5″ apart; no overlap is necessary.

3. When all the required wire netting has been stretched the whole surface is brushed over with a thin mixture of lime mortar to which a quantity of fine chopped jute has been added. This rough-casting gives the plaster which is afterwards applied a better hold of the wire netting.

4. The lime mortar used for the ceiling is mixed in the same way as that for ordinary wall plaster, *i.e.*, one part of lime to two parts sand, except that a quantity of finely chopped jute is added (25 lbs. to every 100 cubic feet of mortar). The lime mortar is applied to the wire netting from above or below, with an ordinary mason's trowel; the first or rough coat being allowed to set partially before the finishing coat is applied.

5. It is not necessary to apply a board or any support above the netting whilst plastering from below.

6. The whole ceiling should be kept wet for several days.

Mud plaster ceiling.

7. The wire netting may be of 1″ mesh and is laid in the manner specified for lime plaster ceilings.

8. The mud plaster will be mixed as specified for ordinary mud plaster. A rough coat will be applied from above or below, and as soon as it has partially set a second layer will be applied below and floated over with a straight edge. When the mud plaster is dry the underside will be leeped.

Boarded ceilings.

9. The boards will be of the best Burma teak, or other wood specified. They must be well seasoned, sound and free from all imperfections.

Boards will be not less than ½″ thick and must not exceed 6″ in width.

10. The boards will be laid truly parallel and fixed to roof purlins or to ceiling joists spaced 2′ apart and fixed to the underside of the tie beams of trusses as may be specified. The joints will usually be tongued and grooved with shot ends, and must be neat and close, the planks being forced up against one another before being fixed. Another form of joint is made by laying the boards thus 

The heading joints will break joint, and the boards will be fixed with nails or screws, two at each end of a board, and one at each intermediate joist, alternately on opposite sides of the board.

11. The underside will be planed smooth, and free from all irregularities, and varnished or painted as directed. The

Boarded ceilings—(contd.). upper side should be painted with solignum in localities where white-ants are prevalent.

Cloth ceilings. 12. The cloth will be stout dungry cloth, and will be fixed on frames, not exceeding $5' \times 5'$, with fillets $\frac{3}{8}'' \times 1\frac{1}{2}''$. The cloth will be damped, stretched over the frame, and fastened with tacks on the inside.

13. The cloth will be whitened with the following mixture:—6lbs. Paris whiting in a covered vessel, with enough water to cover it will be mixed with 1 quart of double size made with China glue, and left in a cool place to cool, till it becomes a jelly, and then diluted for use; 1lb. of jelly is enough for 50 square feet of ceiling.

If the above materials cannot be obtained, the best chalk procurable must be used, ground very fine. Rice size may be substituted for glue in the same circumstances; about $\frac{1}{4}$lb. of rice should make 1 quart of size. On no account should white wash be used, as it soon rots the cloth.

14. The frames will then be screwed to the roof timbers or ceiling joists, and the joint will be covered with moulded fillets of wood, screwed to the frame.

Venesta ceiling. 15. The venesta boards will be $24'' \times 24''$, and $\frac{3}{16}$ inches thick. They will be fixed with screws or nails, as specified, on battens spaced 2′ centre to centre either way, either under the roof purlins or the tie beams of trusses. The joints will be butt joints, and will be covered with moulded fillets of wood screwed to the battens.

16. The underside will be finished off by painting or varnishing as may be specified.

Reinforced Concrete.

Uses. 1. Reinforced concrete can be adopted for many varieties of work, and has many advantages over other materials such as durability, immunity from white-ants and economy in upkeep. It must be remembered that the centering and moulds form a considerable item in the cost, and may determine the advisability of employing this form of construction. Roofs and floors may be made of reinforced concrete slabs, supported either on rolled steel joists or on reinforced concrete beams and pillars of monolithic construction. For verandahs, pillars, rafters and battens may all be of this material. Piles, chowkats, fencing posts, lintels, brackets, etc., can be moulded horizontally and used when seasoned. Its use is also applicable to cul-

verts and bridges, retaining walls for tanks, stands for lavatory basins, stairs, pipes, channels, saddle racks, mangers, etc., etc. Uses—(*contd.*).

2. Calculations for the simpler forms of beams, pillars, slabs, etc., are given in Section 4. For more complicated designs standard works on the subject should be consulted.

The design should aim at including only standard sizes of reinforcement rods, and as few variations in the sections of beams, columns, etc., as possible, to minimise the sizes of moulds required.

3. The concrete will be composed of Portland cement, sand, and aggregate in the proportion of 1: 2: 4 or as otherwise specified. For thin slabs 1: $1\frac{1}{2}$: 3 concrete should be used. For pillars, bedplates, etc., 1: 3: 6 will usually do. The materials and mixing will be as specified for cement concrete. The aggregate will be of hard non-porous stone, graded from $\frac{1}{8}''$ to $\frac{3}{4}''$ gauge, but for small moulded work nothing larger than $\frac{1}{2}''$ gauge should be used. Materials.

4. The type and quantity of reinforcement required varies with each case, and depends on calculation. It may be in the form of steel bars or wire, bars of patent section, or mesh work such as expanded metal. For ordinary work plain bars are suitable and economical. Reinforcement.

Surplus material from Arsenals, factories, etc., should be used as far as possible, otherwise the bars, etc., should be ordered from England or Cossipore.

5. The steel must be clean and free from loose scales, oil or grease of any kind. A thin film of rust so long as it is not scaly or loose is not detrimental. When large bars are used they should be washed over with cement grout before being embedded. Steel which is likely to remain stored some time before use should be whitewashed.

Reinforcing metal must be immersed in water or thoroughly damped before being embedded in the concrete, if it has been exposed to the sun's heat for any length of time.

6. For columns, rods are arranged vertically round the face, and held together with hoops, ties, or spiral coils. The whole must be rigid and the ties tight.

7. For slabs the reinforcement may be of expanded metal or other mesh reinforcement, or a network of rods wired together at intervals along the breadth and length respectively. The reinforcement will be at the bottom of the slab, held firmly in position by blocks or clips which are removed as the concrete is placed. Where the slabs are continuous over beams, rein-

Reinforcement—(*contd.*).

forcement is required in the upper surface over the beams. The rods are bent at the points of contraflexure.

8. For beams rods are embedded in the lower portion to take the tensile stress. When fixed or continuous over points of support, reinforcing rods are also required in the top portion, extending some distance beyond the point of contraflexure as determined by calculation. Some of the rods in the lower portion may be bent up at the points of contraflexure for this purpose.

Shear members composed of steel rods or stirrups are bound to the tension rods at intervals where necessary. The lower bars are fixed by means of hooks suspended from the top; flat iron gauges grip the bars and keep them parallel. As the concrete is filled the hooks and gauges are removed. For ordinary beams and slabs shear reinforcement is usually unnecessary.

9. No reinforcement should be nearer the surface than 1″ for slabs or 1½″ for large beams and columns. The ends of reinforcement bars are turned up ½″ to 1½″ to prevent slipping. Welds are to be avoided as far as possible: if found necessary they are only to be made at points where the steel is stressed as little as possible.

10. The reinforcement will be fixed in exact accordance with the drawings. It will be held in position firmly so that the placing of the concrete will not move it. No concrete will be placed until the reinforcement has been inspected by an officer.

Centerings and mouldings.

11. Will consist of boards 1″ to 2″ thick, framed with battens or carefully designed falsework. The centering must be rigid, well braced, and sufficiently strong to stand the pressure of wet concrete and the stresses of ramming, etc. Struts must rest on firm ground not liable to subsidence.

It should be designed to admit of being easily dismantled and used over again. Bolts are preferable to nails: tongues and wedges should be used where possible. Nails should not be driven home, but the heads left out so that they can be easily withdrawn.

12. Insides of moulds must be planed smooth and thoroughly clean. To prevent the concrete adhering to them, they should be lined with oiled paper, or coated with whitewash, soft soap or oil. Joints must be tight enough to prevent leakage.

13. The timber forming the moulds may have one edge splayed so that if any slight expansion occurs the splayed edge

can slide over the adjacent plank without causing any marked deformation of the concrete surface. Centerings and mouldings—(*contd.*).

14. Moulds for small pieces will generally be of well seasoned wood. For pieces which are required in large quantities it may be economical to make the moulds of metal.

Wooden moulds can generally be used 200 to 300 times before repairs are necessary. For occasional pieces moulds may be made on a level platform of bricks mud plastered.

15. The concrete will be placed in the moulds as soon as mixed (not later than 10 minutes after mixing). It must be worked round the reinforcement and well rammed in layers not more than 3″ deep. Filling concrete.

16. In filling columns the concrete will be poured into the moulds in 3″ layers and constantly puddled with a rod to expel air bubbles. The work must not stop until the column has been completed.

17. The work of filling in beams and slabs should be completed in one operation as quickly as possible. If concreting must be stopped before the work is completed, the concrete in beams will be stopped in a vertical plane over the centre of a support, in slabs in a vertical plane over the centre of a beam.

18. On recommencing to lay concrete, all edges of previously deposited concrete will be thoroughly cleaned, and, if ordered, roughened with a chisel. The edges must then be well flooded with cement grout.

19. The surface of the concrete will be trowelled, rendered with 1 : 2 cement mortar and floated over. The work must be kept in the shade and well watered for 10 days. Small moulded articles will be kept in a tank. Finishing.

20. Centering will not be removed until permission has been obtained from the Officer in charge. The concrete must be sufficiently hard and should ring when struck with a hammer. Striking centering.

21. All centering will be removed carefully in such a way as not to shake or otherwise damage the work.

22. Centering for columns will usually be removed after 7 days, that for floors and sides of beams after 14 days and that for the under sides of beams after 21 days. In striking the centering, the wedges will be loosened 24 hours before the struts are removed.

Where there is no strain on the concrete, the centering may be removed after 24 hours.

In cool damp weather the above periods should be increased.

23. The waterproofing of concrete, especially in roofs, is important. A dense concrete is naturally waterproof. The Waterproofing.

Waterproofing—(*contd.*).

following rules should be followed if water tightness is required: Use (1) Sands of mixed grains. (2) Moderately wet concrete. (3) Sufficient cement. (4) Care in mixing. Concrete may be waterproofed by the addition of 8-12 per cent. of slaked lime to the weight of cement used. Another method is to use alum, about $2\frac{1}{2}$ per cent. dissolved in the water.

24. The addition of up to 10 per cent. of residual petroleum to the cement when mixing has been found to render concrete waterproof. The presence of the oil does not affect the tensile strength; the compressive strength is, however, slightly reduced, while the adhesion is diminished, and it is advisable to use indented bars.

Lime concrete reinforced.

25. Lime concrete should not ordinarily be employed for reinforced concrete work. Reinforced lime concrete roofs have, however, been successfully made at Jhansi. The roofs were supported on rolled steel joists. The lime concrete was reinforced with No. 4, 7 ply galvanised fencing wire. The centering was made up of bullies and rammed earth mud plastered, supported on corrugated iron sheeting.

SECTION IV.

Calculations.

1. Calculations should be as concise as possible consistent with giving all that is really necessary. All calculations should be in accordance with the formulæ, etc., given here and, to ensure facility of reference, they should be submitted in the form given in the examples. **Form of calculations.**

A table giving the notation used will be found at page 90.

2. For transverse stress a factor of safety of 8 is to be taken for timber and 4 for steel. The working strength of timber is given in table 2. For steel, etc., the following table may be used:— **Permissible stresses.**

Material	Transverse strength r	Tension. t	Compression c	Bearing. r_b	Shearing. s	Modulus of elasticity. E
Mild steel	7½	6¼	7	8	5	12,000
Wrought iron	5	5	5	5	4	12,000
Cast iron	3½	1½	8	10	2½	7,500

3. The safe crushing strength of masonry may be taken as:—

Burnt bricks in cement mortar	.10	tons per square foot.
1st or 2nd class bricks in lime or mud mortar	.	Ditto.
3rd class bricks in lime or mud mortar	. 3	Ditto.
Brickwork, sundried-bricks	. 1	Ditto.
Lime concrete	. 5	Ditto.
Gwalior sandstone	.15	Ditto.

4. The following stresses may be allowed for reinforced concrete work, where the concrete is of such a quality that its ultimate crushing strength is 2,400 to 3,000 lbs. per square inch after 28 days and the steel has an ultimate tensile strength of not less than 60,000lbs. and a yield point of not less than 31,000lbs. per square inch:—

Concrete in compression in beams	600	lbs. per square inch.
,, ,, columns	600	Ditto.
,, in shear in beams	60	Ditto.
Steel in tension	16,000	Ditto.
Adhesion between steel and concrete	100	Ditto.

Permissible deflections.

5. The deflection of any beam is not to exceed one-thirtieth of an inch for every foot of span. In the case of beams supporting plastered ceilings, flat mud or concrete roofs or floors of all descriptions, the deflection should not exceed one-fortieth of an inch for every foot of span.

Loads on foundations.

6. For foundations the following loads are not to be exceeded:—

Light loamy soil, or soft clay, dry	·8 tons per square foot.	
Stiff clay, or dry gravel . .	$1\frac{1}{2}$.	Ditto.
Soft rock	3	Ditto.
Hard rock	10	Ditto.

The intensity of pressure should always be uniform throughout a building.

Loads to be allowed for.

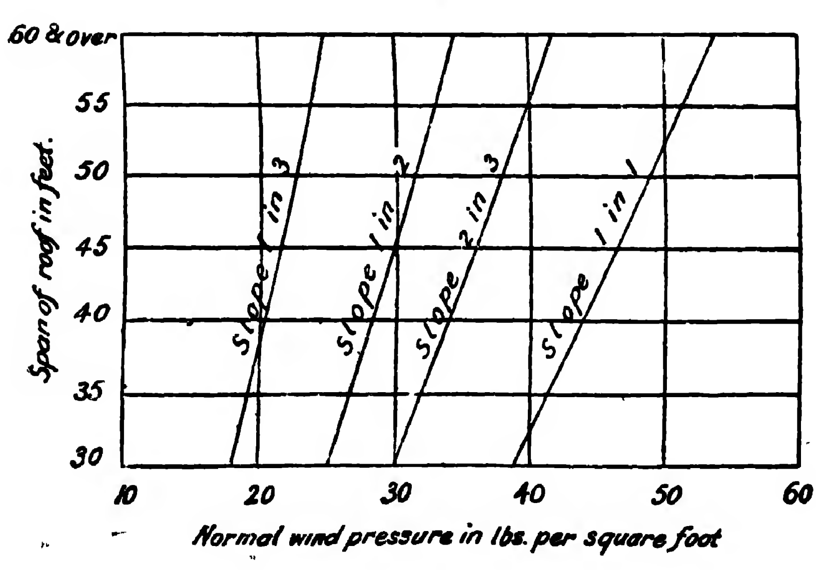
7. In calculating beams, trusses, etc., the temporary loads mentioned below are to be added to the weight of the structure including that of the beam or truss itself.

8. Temporary loads on roofs:—

(*a*) Snow: 5lbs. vertical per square foot for every foot in depth of snow that is likely to accumulate.

(*b*) Workpeople; on sloping roofs 15 lbs. vertical per square foot for roofs up to 20 feet and 1lb. extra for each additional foot of span up to and including 30 feet span. Nothing need be allowed when wind pressure is taken into account. On flat roofs which are only likely to be used by small numbers, allow 30 lbs. per square foot; if the roof is to be used by crowds, loads as for floors should be allowed.

(*c*) Wind pressure; the normal load to be allowed depends on the span and slope and is given in the table:



Wind pressure need not be taken into account for roofs with a slope flatter than 1 in 3, or when the span is less than 30 feet, unless the slope exceeds 1 in 1, when a pressure of 40 lbs. per square foot will be taken. Loads to be allowed for —(*contd.*).

(*d*) The span of a roof, as regards determining the amount of wind pressure or occasional load to be allowed, is to be taken as the internal width of the main portion of the building, irrespective of whether the verandah roof is in the same plane as the main roof or not. In the case of open sheds, as stables, the span should be taken as the distance between the outer pillars.

9. For horizontal ceilings an occasional load of 15 lbs. per square foot is to be allowed for in calculating ceiling joists unless special gangways are made for inspection purposes; this load is not to be taken into account for roof calculations.

10. Temporary loads on floors:—

Barracks and Officers' messes .	112 lbs. per square foot.
Officers' quarters, etc. . .	90 Ditto.

The above are dead loads. For store rooms and factories special calculations must be made: for light machinery, 150 lbs. per square foot may be taken, while for heavy machinery 200 lbs. per square foot will usually be sufficient.

11. The bending moment for a beam of uniform cross section uniformly loaded throughout its length and supported at either end is $\frac{W\,l}{8}$. The moment of resistance for any uniform cross section is $\frac{r\,I}{y}$. To investigate the strength of the beam, it is necessary to equate the bending moment to the moment of resistance, thus Transverse stress.

$$\frac{W\,l}{8} = \frac{r\,I}{y} \text{ or } \frac{I}{y} = \frac{1{\cdot}5\,WL}{r}.$$

For steel sections, where $r = 7\frac{1}{2}$ tons per square inch : $\frac{I}{y} = \frac{WL}{5}$

(W in tons.)

For rectangular beams, where $\frac{I}{y} = \frac{bd^2}{6}$,

$$bd^2 = \frac{9\,WL}{r} = \frac{WL}{m}.$$ (W in lbs.). See table 2, page 92.

For round beams, where $\frac{I}{y} = {\cdot}0982\,d^3$.

$$d^3 = \frac{15{\cdot}3\,WL}{r} = \frac{1{\cdot}7\,WL}{m}.$$ (W in lbs.). See table 2, page 93.

Deflection of beams.

12. The general formula for the deflection of a beam of uniform cross section, uniformly loaded throughout its length and supported at either end is:

$$V = \frac{5\ W\ l^3}{384\ EI} = \frac{22 \cdot 5\ WL^3}{E\ I}$$

For a maximum deflection of one-thirtieth of an inch for every foot of span the formula becomes:

$$\frac{L}{30} = \frac{22 \cdot 5\ WL^3}{E\ I} \text{ or } I = \frac{675\ WL^2}{E}$$

For steel sections, where E = 12,000 tons and W is taken in tons

$$I = \frac{WL^2}{17 \cdot 8}$$

For rectangular beams, where $I = \frac{bd^3}{12}$

$$bd^3 = \frac{8{,}100\ WL^2}{E} = \frac{WL^2}{q}. \quad \text{(W in lbs.). See table 2.}$$

For round beams, where $I = \cdot 0491\ d^4$.

$$d^4 = \frac{13{,}750\ WL^2}{E} = \frac{1 \cdot 7\ WL_2}{q}. \quad \text{(W in lbs.). See table 2}$$

For a deflection of one-fortieth of an inch for every foot of span, the right hand side of the above equations must be multiplied by $\frac{4}{3}$.

For beams otherwise loaded and arranged, see table 3. Values for bd^2, bd^3, d^3, d^4, are given in tables 5 and 6; tables of I and $\frac{I}{y}$ in tables 10 to 12.

The formulæ for strength and deflection (of $\frac{L}{30}$) will give the same results, when $\frac{L}{d} = \frac{q}{m}$ for wooden and 1·78 for steel beams: these figures being multiplied by $\frac{3}{4}$ for a deflection of $\frac{L}{40}$. Below this proportion the strength formula will give the higher result and above it the size of the section will depend on the deflection formula.

Columns.

13. For short columns where the length does not exceed 8 times the least dimension or 30 times the least radius of gyration, the formula is—

$$C = Ac$$

For long columns the value of C in the above formula must be modified in accordance with Fidler's formula.

$$C = A\ \frac{c_1 + \rho - \sqrt{(c_1 + \rho)^2 - 2 \cdot 4\ c_1\ \rho}}{1 \cdot 2}$$

where c_1 = ultimate compressive strength: for timber the safe stresses given in table 2 should be multiplied by 8, Columns (*contd.*).

$$\rho=\pi^2 E\times\left(\frac{k}{l}\right)^2 \text{ for rounded ends.}$$

$$\rho=\pi^2 E\times\left(\frac{10}{6}\frac{k}{l}\right)^2 \text{ for fixed ends.}$$

$$\rho=\pi^2 E\times\left(\frac{10}{8}\frac{k}{l}\right)^2 \text{ for one end fixed and one rounded.}$$

for rectangular wooden struts $k = \cdot 289\ b$.

The maximum length of any strut or column is not to exceed 45 times its least dimension or 150 times its least radius of gyration. Principal rafters of trusses may be calculated as half fixed; struts as with rounded ends.

See tables 7 to 12 for steel and timber struts.

14. Where A is the net sectional area after deducting for rivet holes or portions cut away: Tension and shear.

$$T = At \text{ and } S = As.$$

The diameter of a rivet hole should be taken as the diameter of the rivet plus $\frac{1}{8}''$.

Table 15 gives the tensile strength of iron and steel bars.

15. No general formula is given for beams under combined bending and tensile or compressive stress. A section must be assumed and the intensity of the stress at the extreme fibres investigated. The fibre stress must be kept within the limits permissible. Combined stress.

For rectangular beams the simplest method will be to work out the breadth and depth to resist the transverse stress alone and then, using the depth thus found, to ascertain, the additional breadth necessary to resist the direct stress.

In other cases a section must be assumed: ascertain the percentage of the section required to resist the transverse stress; the percentage remaining must be capable of resisting the direct stress.

When a rafter, etc., is calculated for direct as well as the transverse stress, its deflection need not be considered.

When a strut is under transverse stress, the beam, etc., which brings on the stress will usually prevent any liability to bending in the direction of the plane of the roof. In such cases, when calculating the resistance to compression, k (para. 13) may be taken as about an axis normal to the load, from the formula $k=\sqrt{\frac{I}{A}}$, should this value prove greater than the minimum value of k given in the tables. Similarly for wooden beams the least dimension may be taken as d instead of b.

General rules for rafters, etc.

16. When calculating wooden and steel battens, rafters and purlins, the vertical load is to be reduced to normal by multiplying it by the cosine of the angle of slope. In the case of ridgepoles, which take up the tangential pull in the rafters, in addition to carrying a normal load, the vertical load should not be resolved to normal.

17. Purlins, which directly carry the roof covering, *e.g.*, sheet iron, or a sloping ceiling, also battens and rafters, are often continuous over two, or more spans, but in order to allow for the stress due to the vertical portion of the load resolved down the slope and to avoid the lengthy calculation that is involved, they should be treated as supported beams.

18. Purlins carrying rafters or corrugated iron roofs, where the span is not very great, are not affected by the tangential pull in the plane of the roof, provided that the rafters or corrugated iron are securely fixed at the ridge and the eaves. They may be treated as continuous beams and calculated for transverse stress only. Where purlins are not actually continuous over trusses, care must be taken to make the joints so that continuity is secured as far as possible: wooden purlins should be halved into one another and spiked or bolted into the truss or wall plate, while for heavy purlins fish plates must be given; steel purlins should be connected by fish-plates whose width is equal to the depth between the flanges of the beams and two bolts or rivets should be used on either side of the joint. Where heavy purlins are used over long spans, to prevent their sagging in the plane of the roof, a tie-rod should be taken through the web from the centre of the span to the ridge and joined to a corresponding rod on the other side.

19. For purlins, which directly carry the roof covering, and for battens the proportion of b to d should be from 2 to 3 to 1 to 1 depending on the steepness of the slope. For purlins, which carry rafters or corrugated iron, ridgepoles and rafters the proportion of b to d should be 1 to 2, but, where beams are well fixed to prevent lateral motion, a deeper section may be used, b being $1\frac{1}{2}''$ to $2''$ as a minimum according to the nature of the wood used. Bressummers carrying sloping roofs should be placed vertical and made square or nearly so: this rule applies to verandah wall plates under transverse stress.

20. In heavy roofs, to secure the maximum economy in rafters and battens, the rafters should be roughly spaced in accordance with the following rule:—

$$\text{Spacing} = \frac{\text{span}}{4} + 6''.$$

It has been found in practice that, to prevent warping and sagging and to preserve evenness of appearance, battens should not be less than $1'' \times 1\frac{1}{2}''$ if of teak or sal, or $1\frac{1}{4}'' \times 1\frac{1}{2}''$ if of deodar; in either case the maximum span should be allowed subject to the economical spacing referred to above. General rules for rafters, etc.—(contd.).

21. As it is usually not economical to load trusses anywhere except at the joints, the form of truss to be adopted will depend on the span considered suitable for rafters or corrugated sheets. For rafters a span of 8 feet should rarely be exceeded. For corrugated iron sheets supported at their ends the maximum spans should be $4\frac{3}{4}$ feet for 22 gauge and 4 feet for 24 gauge: if adjoining sheets are overlapped 9 inches and connected together by a double row of rivets, these spans may be increased to $5\frac{1}{2}$ and 6 feet respectively. Thus for spans up to 14 feet collar beams or coupled rafters are suitable: for spans up to 28 feet kingpost trusses may be used: for spans over 28 feet steel trusses are to be preferred. General rules for trusses.

22. The most economical spacing for a kingpost truss may be taken as $=\frac{\text{span}+4\frac{1}{2}}{3}$; for steel trusses a good general rule is, spacing $=\frac{\text{span}+36'}{7}$. If a ceiling is given requiring special ceiling joists, these spacings should be slightly reduced.

23. In each case

Wooden trusses.

W = load on the truss or pair of rafters $= wLD \sec \theta$

W_1 = load due to horizontal ceiling $= w_1 LD$.

Where L is the span and D the spacing of the trusses: w, w_1 the weight per square foot of the roof covering and ceiling.

(*a*) Coupled rafters, collar-beams and couple close roofs. Compression in rafter $=\frac{1}{2} W \operatorname{cosec} \theta = C$.

Tension in tie-beam, if provided, $=\frac{1}{2} W \cot \theta = T = C \cos \theta$.

(*b*) Kingpost trusses: it is assumed that the common rafters rest side by side on a ridge pole and are not continuous over the purlins.

Compression in principal $=\frac{3}{8} W \operatorname{cosec} \theta + \frac{1}{4} W_1 \operatorname{cosec} \theta = C$.

Tension in tie-beam $=\frac{3}{8} W \cot \theta + \frac{1}{4} W_1 \cot \theta = T = C \cos \theta$.

Compression in strut $=\frac{1}{8} W \operatorname{cosec} \theta$.

Tension in kingpost $=\frac{1}{4} W + \frac{1}{2} W_1$.

24. Coupled rafters and rafters that butt against one another at the ridge are subject to a higher degree of compression than ordinary rafters: to calculate them as beams under combined stress would be laborious and a sufficiently accurate result can usually be obtained by treating them as supported beams, taking W as the vertical load instead of as the normal load. Where rafters

Wooden trusses—(*contd.*).

are united by a collar, it must be understood that the collar, wherever it is placed, in no way relieves the rafter of transverse stress: the object of the collar is to take up the thrust on the walls and, for this purpose, the lower it is placed the better; it should only be placed one-third or half-way up to the raiter, when the extra head room thus obtained is essential.

25. Calculations for wooden trusses may be limited usually to working out the sizes of the principal rafter, the heel strap and heel bolt. If a steel or iron tie-rod is to be used, it should also be calculated. If the tie-beam carries a ceiling, it should be calculated as a supported beam for a deflection of $\frac{L}{40}$. The most economical section for the principal rafter, if it is only subjected to direct stress, is square and this section should be used with a tie-rod; but in practice the width of the tie-beam is made the same as the width of the principal and it is therefore usual to make the principal rather deeper than wide, but the depth should not usually be more than twice the width.

26. Wrought iron tie-rods are to be preferred to steel, if, in order to obtain the correct length, welding is necessary. Unless the ends are upset to take the screw thread, the tie-rod should be calculated as with "minus" threads, *i.e.*, for the section at the base of the threads, see table 15.

Joints in wooden trusses.

27. For section of the strap at the heel of the principal rafter, if T is the tension in the tie-beam:

$$A = \frac{T}{2t}.$$

five-eighths of this effective section is to be given on either side of the eye, if the ends are forged, otherwise the area of the bolt hole must be added to the area found necessary to resist the stress.

$$\text{Diameter of bolt at foot of rafter} = \frac{T}{b \times \frac{5c}{3}}.$$

Steel trusses.

28. The stresses in steel trusses must be obtained from diagrams. Where wind pressure is allowed for and one end of the truss is free to move, the diagram should usually be drawn on the assumption that the wind is blowing on the side of the truss with the fixed end. In special cases a diagram is also to be drawn on the assumption the wind is blowing on the free side of the truss.

Table 14 may be used for symmetrical Fink trusses, resting on walls and symmetrically loaded at the joints.

29. Though in the calculations for wooden trusses it is unnecessary to consider the weight of the purlins and of the

truss itself, for steel purlins and trusses this item must be taken into account. The weight of a steel truss in lbs. may be taken as $= \cdot 08 \text{ DL}^2$. Steel trusses —(*contd.*).

30. The principal of a steel truss may consist of a single tee or a pair of angles back to back. Struts may consist of single or double angles or tees. Ties of small trusses usually consist of a single flat: for larger trusses, to ensure stiffness during erection or in open sheds, etc., where a reversal of stress may occur, the ties should consist of single or double angles. If a reversal of stress is likely to occur, trusses should be cross connected at joints of the tie-beam. When one member of a truss is made double, it is usual to make all the members double, in order to avoid the eccentricity in stresses that would otherwise occur. Double members should be connected together at one or more points intermediate between joints by means of a rivet and a small filling piece, equal in thickness to the gusset plate: for struts the distance apart of these connections should not exceed the unsupported length of a single strut capable of resisting half the stress. Single gusset plates of the same thickness as the truss members are required for trusses with double members and double cover plates $\frac{1}{4}$ inch thick for trusses with single members. No member in a truss should be less than $\frac{1}{4}$ inch thick and no plate or flange through which a rivet passes should be less than 2 inches wide, if $\frac{5}{8}$ inch rivets are used. Rivets should not usually be less than $\frac{5}{8}$ inch diameter. All members of a truss should, as a rule, be of the same thickness, otherwise packing pieces must be used where necessary.

31. When appearance is of importance, the tie-beam of a steel truss should be given a camber of about 1 in 20 to 1 in 30. The tie-beam of a large truss, where it is considered that a horizontal tie-beam may be allowed, should always be given a slight camber during construction, in order to counterbalance the deflection that will occur when the truss is loaded up. It should be remembered that the provision of camber reduces the depth of the truss and therefore increases the stresses in the members.

32. Trusses should be securely held down especially in the case of light roofs and open sheds. For trusses up to 30 feet span no provision need be made for expansion and contraction: between 30 and 60 feet span it is usual to pass the holding down bolts at one end of the truss through slotted holes in the base-plate. For large trusses over 60 feet span it is necessary to provide rollers or Muntz metal plates at one end in order to allow the truss to move freely in a horizontal plane. It must be remembered that the end, at which provision is made for expansion and contraction, can only supply a vertical reaction:

Steel trusses—(concld.). any horizontal stress due to wind pressure, etc., must be taken up at the fixed end. In trusses supported on stanchions expansion joints are impracticable, unless the stanchions are strutted.

Rivetted joints. 33. For shearing $N = \dfrac{C \text{ or } T}{\pi \times \dfrac{d^2}{4} \times s}$ for bearing. $N. = \dfrac{C \text{ or } T}{d \times t_p \times r}$;

where N=number of rivets required.

The largest number of rivets given by either of the above formulæ is to be used : see table 13.

The diameter of the rivets to be used depends on the thickness of the plates : it is usual in first class practice to use $\frac{5}{8}$ inch rivets with $\frac{1}{4}$ inch plates and $\frac{3}{4}$ inch rivets with $\frac{3}{8}$ inch plates. Rivets of the same size should be used throughout any particular truss, etc.

The pitch or distance from centre to centre of rivets should usually be 3 times the diameter of the rivet and should never be less than twice the diameter. The distance from the end of a bar to the edge of a rivet hole should usually be twice the diameter and never less than the diameter of the rivet.

Beams in floors or flat roofs. 34. The most economical arrangement of any system of main and secondary beams is given by the following rough rule :

$$D = \frac{L + D_1}{4}.$$

when D, L = spacing and span of main beams.

D_1 = spacing of secondary beams.

The nearest higher value of D should be used.

35. When subsidiary steel beams are joined to main beams the angle connections should be designed to take up the stress. A pair of steel beams used side by side under transverse stress should be connected by separators placed 5 to 6 feet apart ; separators, which can be obtained ready made, should also be used immediately under any concentrated loads. Designs of type connections and separators are given in manufacturers' catalogues.

36. Light floor beams embedded in walls and provided with a stone bedplate above and below may be treated as half fixed; *i.e.*, their deflection may be neglected and they may be calculated for strength as supported beams. Subsidiary beams resting on main beams may be treated in the same way, if connected as described for purlins in paragraph 18. Subsidiary beams connected to the flanges of main beams should be treated as supported only.

37. The rise of arch should be one-eighth of the span: the span should be between 4 and 6 feet. **Jack arches.**

The section to be given for the tie-rods may be found from the following formula:

$$T = \frac{1{\cdot}5wL^2}{R}$$

Where T = thrust of the arch in lbs. per lineal foot, which has to be resisted by the tie-rods. w = weight per square foot of live and dead load supported by the arch for end spans and of the extra super-imposed load only for intermediate spans.

L = span of arch in feet. R = rise in inches.

The spacing of the rods is not to exceed twenty times the width of the supporting beams.

End span rods must always be used: intermediate span rods need only be used when large concentrated loads are anticipated.

38. The material in steel and wooden beams is homogeneous throughout and, if a beam is made strong enough to resist the maximum bending moment, it will safely resist any negative bending moments at the supports and also, as a general rule, the shearing stresses. Reinforced concrete is a composite substance and failures are likely to occur, unless care is taken to investigate the design of a beam, etc., in every particular, having due regard to the external conditions, *i.e.*, the methods of loading and supporting, and to the internal structure, *i.e.*, the position of the steel re-inforcement provided to resist bending and shear. The design of simple columns, beams and slabs presents no great difficulty, but for more complicated structures a thorough knowledge of the subject is essential. Apart from accurate designing, the employment of good materials and careful supervision are absolutely necessary. **Reinforced concrete. General.**

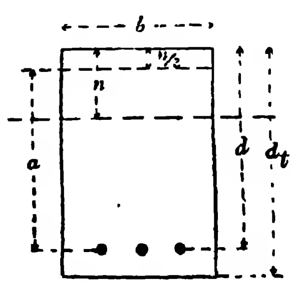
39. The general formulæ for rectangular beams are:— **Rectangular beams.**

(*a*) with single reinforcement.

$$n = d\{\sqrt{{\cdot}3\,p + ({\cdot}15\,p)^2} - {\cdot}15\,p\}$$

$$c = \frac{2 \times \text{bending moment}}{b\,n\,(d - \frac{n}{3})}$$

$$t = \frac{50\,c\,n}{p\,d}$$



Reinforced concrete. Rectangular beams—(*contd.*).

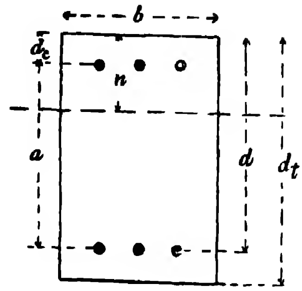
(*b*) With double reinforcement.

$$n=\sqrt{\cdot 3d\,(pd+p_c d_c)+\{\cdot 15d\,(p+p_c)\}^2}-\cdot 15\,d\,(p+p_c)$$

$$c=\frac{2\times\text{bending moment}}{bn\,(d-\frac{n}{3})+\left\{\cdot 3\,p_c\,b\,d\times\frac{n-d_c}{n}\times(d-d_c)\right\}}$$

$$t=15c\,\frac{d-n}{n}$$

$$c_s=15c\,\frac{n-d_c}{n}$$



40. For a uniformly loaded and supported beam, these formulæ may be put into the form :

$$b\,d^2=\frac{WL}{m}\quad W\text{ in lbs.}$$

where m has the following values, it being assumed that $d_c=\frac{n}{3}$

	Percentage of tensile reinforcement.									
	¼	½	¾	1	1¼	1½	1¾	2	2½	3
$A_c=0$ . .	25	48	67	72	77	81	85	88	93	96
$A_c=\cdot 2A_t$ . .	25	48	69	77	83	88	94	98	106	112
$A_c=\cdot 4A_t$ . .	25	48	69	82	89	96	102	108	119	127
$A_c=\cdot 6A_t$ . .	25	48	69	87	96	104	112	118	132	142
$A_c=\cdot 8A_t$ . .	25	48	69	92	102	112	122	130	145	157
$A_c=A_t$ . .	25	48	69	94	109	121	131	141	157	171
$A_c=1\frac{1}{2}A_t$ . .	25	48	69	95	115	138	156	171	196	219
$A_c=2A_t$ . .	25	48	69	96	119	142	165	188	234	276

b should usually be taken as equal to ·6 d : d, it must be remembered, is the effective depth, *i.e.*, from the top of the concrete to the centre of gravity of the reinforcing steel.

41. The effective span is to be taken as the distance between centres of bearings: for continuous beams the effective span is the distance between centres of supports: for beams resting on walls, the depth of the section should be added to the clear span to obtain the effective span. **Reinforced concrete. Rectangular beams—(contd.).**

42. With a uniformly distributed load, the bending moment for a supported beam is $1\frac{1}{2}$ WL inch-lbs. For beams continuous over more than 2 spans the bending moment may be taken as WL both at the supports and at the centre of span and W in the formulæ should be multiplied by $\frac{2}{3}$. For beams embedded in walls a bending moment of $1\frac{1}{4}$ W L may be taken and W in the formulæ multiplied by $\frac{4}{5}$ at the centre and by $\frac{2}{3}$ at the supports. Bending moments at supports are negative, *i.e.*, the upper surface of the beam is in tension. It should be clearly understood that to consider a beam as supported and to calculate it only for the bending moment at the centre of the span may lead to a failure: in many cases the beam may be more or less fixed at its ends and the negative bending moments that may occur there must be provided for.

43. In singly reinforced beams the concrete and the steel are stressed to their permissible limits, when p is equal to ·675: this is often termed the "economical percentage." If, however, the relative costs of the steel and cement are taken into account, it will be found that, within limits, the higher the percentage and the greater the amount of compressive reinforcement, the more economical the beam. The percentage of tensile reinforcement should not usually exceed 2 and A_c should not be more than A_t. Beams moulded away from the work should always be reinforced on both sides in order to prevent fracture during handling.

44. Reinforcing rods should have a clear space between them of at least 1″ horizontally and $\frac{1}{2}$″ vertically except at joints or at points where the bars are in direct contact and transverse to one another: the distance to the sides or bottom of the beam should be not less than $1\frac{1}{2}$ diameters, subject to a minimum of half an inch clear covering over the steel. For large important beams, or where fire protection is of importance, the outer edge of the concrete should be 2 inches away from the outer edge of the bars. Joints should be made at points where the stress in the steel is a minimum: it is sufficient to lap the bars for a distance of 24 diameters and to bind with fine wire.

Note.—Example 9 of the calculations for a reinforced concrete floor has not been corrected in this respect but the revised rules should be followed in calculating the width of rib required. Instead of placing the rods in one row as in the examples it might be better to place them in two rows.

45. When for any reason the breadth and depth of a beam are fixed and it is desired to find A_t and A_c, the formula in para. 40

Reinforced concrete. Rectangular beams—(*concld.*).

may be solved for m and the table used or the following method may sometimes be found useful. The moment of resistance for a beam with p=·675 is 95 bd^2: subtract this from the bending moment: steel reinforcement will then be required to resist the excess bending moment:

$$A_t^1 = \frac{\text{Excess bending moment}}{16000\ (d-d_c)}$$

$$A_c = A_t^1 \times \frac{\cdot 64\ d}{\cdot 36\ d - d_c}$$

$$\text{Total } A_t = A_t^1 + \frac{\cdot 675\ bd}{100}$$

d_c may be taken as 2″.

Slabs.

46. Slabs are calculated as beams, a strip 12″ wide being considered. When a slab is continuous for more than two spans or when it is supported or continuous over four sides, the bending moment is reduced and W in the formulæ given may be multiplied by:

(*a*) $\frac{2}{3}$ if continuous for more than two spans.
(*b*) X if supported on all four sides.
(*c*) $\frac{2}{3}$ X if continuous on all four sides.

where X has following values, L_1 being the length and L_2 the breadth of the slab:

·5 if $L_1=L_2$	·84 if $L_1=1\frac{1}{2}\ L_2$	1 if $L_1=2L_2$
·71 „ $=1\frac{1}{4}\ L_2$	·9 „ $=1\frac{3}{4}L_2$	

For end spans read $\frac{4}{5}$ for $\frac{2}{3}$ in (*a*) and (*c*) or make these spans shorter.

In cases (*b*) and (*c*) the slab is calculated for the shorter span, L_2. Where $L_1=L_2$, an equal amount of reinforcement should be provided in either direction. Where L_1 is greater than L_2 about half the area of steel given in the direction of L_2 should be provided along L_1. It is always an advantage to reinforce slabs in both directions especially where heavy concentrated loads are expected.

When independent reinforcing bars are provided in one direction only, distributing bars should be provided on the top of the lower tensile bars at right angles thereto. Such distributing bars are not to be further apart than 18″ or four times the effective depth of the slab whichever is least and to have an aggregate cross sectional area of at least 0·08 per cent of the effective cross sectional area of the slab and the diameter of each bar should not be less than $\frac{1}{16}$ of the effective depth of the slab.

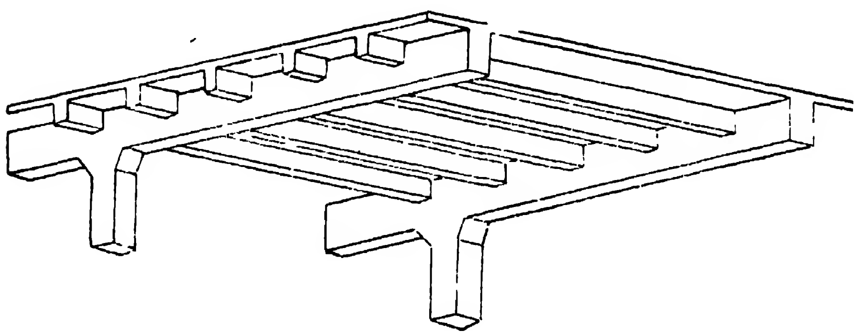
47. Slabs are rarely doubly reinforced, except in the case of culverts, etc., where the depth may have to be limited. Where heavy loads have to be provided for, the depth of the slab should be

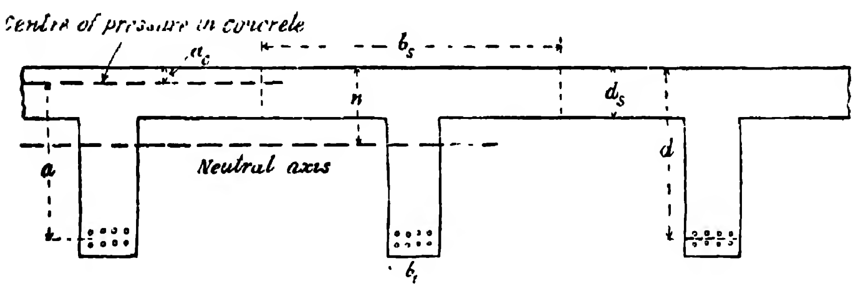
Reinforced concrete. Slabs—(*contd.*).

between $\frac{L}{10}$ and $\frac{L}{15}$: for light floors the depth may be as small as $\frac{L}{25}$, but practically nothing smaller than a 3″ slab, with d= 2″, should be used.

Tee beams.

48. When reinforced concrete is used for an upper floor, it is usual to construct it of a thin slab resting on beams monolithic with the slab : the slab may be carried on main beams, which span from support to support or on secondary beams between the main beams, thus :





Another method is only to use beams between pillars in either direction, thus taking full advantage of the great strength of a slab continuous on all four sides : the pillars are usually placed at the corners of squares. A development of this method that has been adopted very generally in America, is to omit the beams altogether, thereby arriving at a slab continuous over columns at its four corners : the slab is reinforced in four directions, from column to column both ways along the edges as well as diagonals between columns at opposite corners : the column head is cantilevered out to reduce the span of the slab : the advantages claimed for this method are simplicity of construction and economy in centering.

49. For tee beams, the depth of the slab is calculated as explained in para. 46. The main and secondary beams may both be assumed to receive assistance from the slab they support and can be considered as tee beams. Where a deep beam is used with a relatively thin slab, little advantage is to be gained from this

Reinforced concrete. Tee beams—(*contd.*).

method and heavy main beams are often calculated as ordinary rectangular beams, d being measured to the top of the slab. It is also open to question whether the slab can be considered as acting as the upper flange of the main beams when it has already been taken into consideration when calculating the secondary beams. b_s, the width of the slab considered to be acting with the rib, should not exceed the following limits :—

(*a*) One-third of the span.

(*b*) 15 times the depth of the slab.

(*c*) three quarters of the spacing of the beams.

d, the effective depth, should be taken at between $\frac{1}{12}$ and $\frac{1}{18}$th of the span. b_r, the breadth of the rib, must be wide enough to take the reinforcing bars and should not be less than $\frac{b_s}{6}$.

50. When the neutral axis does not fall below the slab, the formulæ in para. 39 apply. When the neutral axis falls in the rib, the following formulæ must be used :

(*a*) with single reinforcement :—

$$n = \frac{d^2_s + \cdot 3pd^2}{2d_s + \cdot 3pd.}$$

$$a_c = \frac{3\ d_s n - 2\ d_s^2}{6\ n - 3\ d_s} \ : a = d - a_c$$

$$c = \frac{2 \times \text{bending moment} \times n}{b_s \times d_s \times (2n\text{-}d_s) \times a.}$$

$$t = \frac{\text{bending moment}}{A_t \times a}$$

(*b*) with double reinforcement :

$$n = \frac{d^2_s + \cdot 3d\ (pd + p_c d_c)}{2d_s + \cdot 3d\ (p + p_c)}$$

$$c = \frac{\text{bending moment} \times n}{b_s d_s (n^2 - nd_s + \frac{d_s^2}{3}) + \cdot 15 b_s d \{p_c (n - d_c)^2 + p\ (d - n)^2\}}$$

$$t = 15\ c\frac{d-n}{n} : \text{and } c_s = 15\ c\frac{n-d_c}{n}.$$

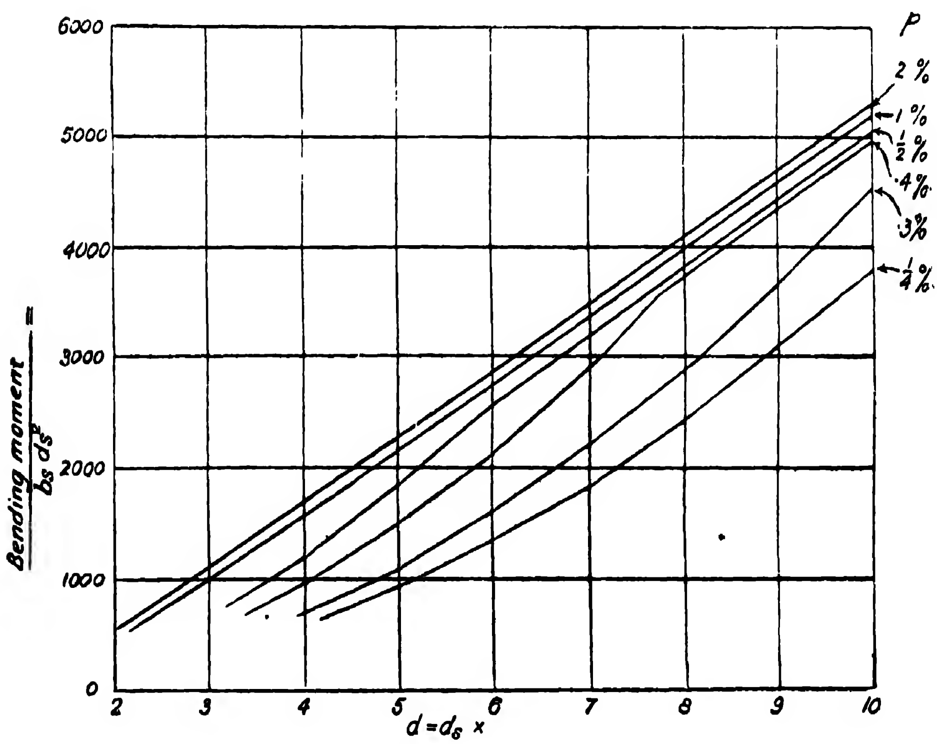
51. By the following procedure the depth of the rib and the reinforcement necessary can be found easily.

Find p and d by the formula given in para. 40, b_s being substituted for b and W being multiplied by $\frac{2}{3}$ in the case of continuous

beams. If the proportion of $\frac{d}{d_s}$ does not exceed the following values, the neutral axis does not fall below the slab and the design may be accepted ; **Reinforced concrete. Tee beams—(*concld.*).**

p=	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1
$\frac{d}{d_s}$ =	4·16	3·12	2·67	2·38

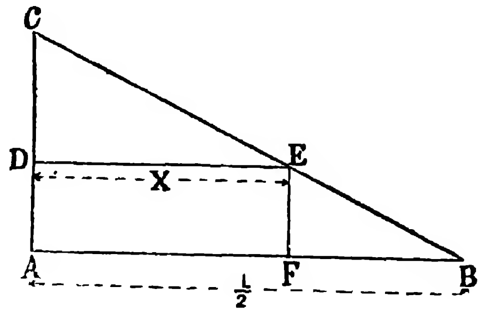
If this proportion is exceeded, the neutral axis falls in the rib and p and d must be obtained from the curve given below. To use the curve evaluate, $\frac{\text{bending moment in inch lbs.}}{b_s d_s^2}$: the proportion of d to d_s can then be read off for any percentage of tensile reinforcement. It will be observed that an increase of p over $\frac{1}{2}$ means very little reduction in the depth of the beam.



52. At the supports, the bending moment being negative, the flange can no longer be considered as acting with the rib and the section must be regarded as an ordinary beam of width b_r. As the area of the concrete, available for resisting compression, is now much reduced either the beam must be deepened towards the support or additional compressive and tensile reinforcement added as described in paragraph 45.

Reinforced concrete. Shear.

53. In a beam, uniformly loaded with w lbs. per foot run, the shearing stress is equal to the reaction, $\frac{wL}{2}$, at the support and gradually diminishes to nothing at the centre of the span. Thus if A is the support, $AB = \frac{L}{2}$ and $AC = \frac{wL}{2}$, then the shearing stress at any point F will be represented by EF,



while the total shearing stress over the half span will be represented by the triangle CAB. Concrete can safely resist a shearing stress of 60 lbs. per square inch, which is considered as distributed over an area b a : then if AD is made equal to 60 b a, the figure ADEB will represent what the concrete can resist. If AD is less than AC, web reinforcement must be provided to resist the excess shear, represented by triangle CDE.

(1) Then at support . . $S = Ac = \frac{wL}{2}$ lbs.

(2) at X feet from support $S = EF = w\left(\frac{L}{2} - X\right)$ lbs.

(3) over the half span . $S = \frac{AC \times AB}{2} = 1{\cdot}5\ wL^2$ inch-lbs.

(4) Excess over a length $S = \frac{CD \times ED}{2}$

$$= \frac{6}{w}\left(\frac{wL}{2} - 60\ ba\right)^2 \text{ inch lbs.}$$

54. Slabs do not ordinarily require any shear reinforcement, nor as a rule do singly reinforced rectangular beams, though it is usual always to turn up half the tensile reinforcement in all beams at a distance not exceeding $\frac{L}{4}$ from the support. Tee beams and all doubly reinforced beams must always be tested for shear, thus :

$$s = \frac{S \text{ at support}}{ba} = \frac{\cdot 568\ wL}{bd}$$

where a is taken as $= \cdot 88$ d and b_r is substituted for b in the case of tee beams. If s exceeds 60 lbs. per square inch web reinforcement must be given : if s exceeds 120 lbs. per square inch, b or b_r should be increased.

55. Web reinforcement is provided for by either turning up not more than half the tensile reinforcing bars towards the support at a distance of not exceeding $\frac{L}{4}$ from that point at an angle θ to the horizon or by means of vertical stirrups. In ordinary beams provision is only necessary for the excess shear, but in important beams stirrups are provided to take up the whole shear, some of the tensile reinforcing bars being turned up as well. **Reinforced concrete. Shear—** *(contd.).*

Bars turned up will be in direct tension and

$$A_s = \frac{S}{16{,}000\ a \sin\theta} = \frac{S}{14{,}080\ d \sin\theta}$$

if $\theta = 45°$, $A_s = \frac{S}{10{,}000\ d}$

with vertical stirrups, the steel is in shear and

$$A_s = \frac{S}{12{,}800\ a} = \frac{S}{11{,}280\ d}$$

S is taken from 53 (3) or (4) as the case may be, while X may be found by equating, 60 ba=52·8 bd in 53 (2), whence

$$X = \frac{CD \times AB}{AC} = \frac{L}{2} - \frac{52{\cdot}8\ bd}{w} \text{ feet.}$$

and excess shear $S = \frac{6}{w}(\frac{wL}{2} - 52{\cdot}8\ bd)^2 = 6\ wX^2$ inch.-lbs.

If provision for the whole shear is required X is taken as $\frac{L}{2}$ *vide* 53 (3).

56. Each vertical stirrup has two limbs and stirrups are often provided in pairs. Having found A and the minimum number of stirrups required (N) the area of one stirrup can be ascertained. The stirrups are of equal size and as they resist the same amount of shear, they are spaced so as to divide the triangle D C E into an equal number of parts, being closer together at the supports than towards the centre of the span. A graphic method of finding the spacing is given in the examples: the same thing is given by the following formulæ:

$$\text{Support to No. 1 stirrup} = \frac{X}{\sqrt{N+1}}\left(\sqrt{N+1} - \sqrt{N}\right)$$

$$\text{No. 1 to No. 2 stirrup} = \frac{X}{\sqrt{N+1}}\left(\sqrt{N} - \sqrt{N-1}\right)$$

$$\text{No. (N—1) to No. N stirrup} = \frac{X}{\sqrt{N+1}}\left(\sqrt{2} - 1\right)$$

Reinforced concrete. Shear—(*concld.*).

The spacing must never exceed d and in important beams it is usual to carry the stirrups at this spacing across the centre of the span. The minimum number of stirrups permissible may be found by the formula

$$N = \frac{24 \cdot 6X^2}{d^2}$$

Reinforced concrete. Adhesion.

57. The adhesion stress along the reinforcing bars is equal to $\frac{\cdot 568\ wL}{Od}$ and should not exceed 100 lbs. per square inch, otherwise smaller and more numerous bars must be used. Important beams should always be tested for adhesion. The ends of all bars, for whatever purposes used, must be split or turned over.

Reinforced concrete Columns.

58. In calculating the load on a column brought on by a continuous beam, it must be remembered that the end reactions are each equal to one-third of each intermediate reaction. The length of a column should not ordinarily exceed 18 times its least dimension.

59. Two forms of column are usually employed :—

(*a*) Square or circular columns reinforced with, 4 for square and 6 for circular, longitudinal rods, whose area amounts to not less than ·8 per cent of the effective area of the column measured between the outer edges of the rods: the rods are bound together with wire, etc., at intervals not exceeding 9 inches or 15 times the least dimension of the rods, this interval being increased to double the above amount at the ends. For this type :

$$C = 600\ A\ (1 + \cdot 14\ p) = A\ c$$

en A is the effective area of the column and p the percentage of longitudinal reinforcement. The value of c may be taken as follows :—

	Percentage of reinforcement.								
	½	¾	1	1½	2	2½	3	4	5
c= .	642	662	684	725	768	810	862	936	1020

(*b*) Circular columns composed of 6 or more longitudinal rods enclosed in a helical binding. The longitudinal reinforcement should not be less than ·8 per cent. or more than 4 per cent. and the helical binding should not exceed 3 times this amount with a minimum of ½ per cent.

The pitch of the helix, r, should be between $\frac{1}{8}$ and $\frac{1}{8}$ d, the internal diameter of the helix. **Reinforced concrete. Columns—(contd.).**

$$C = \frac{700\pi d^2}{4}(1+\cdot14p)=550\ d^2(1+\cdot14\ p)$$

where $p=p_h+p_l$, the sum of the percentages of reinforcement in the helix and the longitudinals.

For the section of steel required for the helix

$$A_h=\frac{\text{volume of helix}}{\text{length of helix}}=\frac{12\,L\times\frac{\pi d^2}{4}\times\frac{p_h}{100}}{\frac{12L}{r}\sqrt{\pi^2d^2+r^2}}=\frac{r\,p_hd^2}{127\sqrt{\pi^2d^2+r^2}}$$

60. For long columns with fixed ends where l exceeds 18 times d, the least dimension, c must be reduced thus :—

	Ratio of l to d			
	21	24	27	30
c ×	·8	·6	·4	·2

If the ends are not fixed c must be further reduced, thus :—

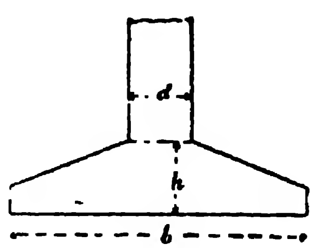
One end hinged, one end fixed . . $c\times\cdot5$

both ends hinged . . . . . . $c\times\cdot25$

One end fixed, one end free . . . $c\times\cdot0625$

61. The base of a column is usually made square, the area required being found by dividing the weight of the column and base plus the load supported by the pressure per unit area that the soil can support safely.

The height, h, of the base of the column above the bottom of the foundation slab must be sufficient to prevent any tendency for the column to shear through the slab and is found thus :



$$h=\frac{W-\cdot25\pi d^2r}{\pi ds}$$

where W is in lbs. r is the resistance per square inch offered by the oil and s the safe shearing stress per square inch=60 lbs.

Reinforced concrete. Columns—(*concld.*).

The bending moment in the foundation slab is equal to $\frac{W}{8}(b - \cdot 85\ d)$

b and d being in inches, W in lbs.

NOTATION.

Notation.

A=any area in sq. inches: area of reinforcement in R. C. beams, etc. $= \frac{pbd}{100}$.

A_c, A_h, A_l, A_s, A_t=area in sq. inches of reinforcement in R. C. beams, etc., respectively for compression, helix in columns, longitudinals in columns, shear and tension.

a=lever arm in R. C. beams$=d - \frac{n}{3}$ for rectangular and $d - a_c$ for tee beams.

a_c=distance in R. C. beams from the upper edge to the centre of pressure of concrete.

b =breadth of any beam, etc., in inches.

b_r=breadth in inches of the rib in a R. C. tee beam.

b_s=effective breadth in inches of the slab in a R. C. tee beam.

C, c=total amount and intensity per sq. inch respectively of compressive stress.

c_s=compressive stress per sq. inch in steel in doubly reinforced R. C. beams.

D=distance apart in feet, centre to centre, of beams, trusses, etc.

d =depth in inches of any beam, etc.: for R. C. beams the effective depth, from the upper surface to the centre of gravity of the tensile reinforcing bars.

d_c=depth in R. C. beams from the upper surface to the centre of gravity of the compressive reinforcing bars.

d_s=depth of slab in R. C. tee beams.

d_t=total depth, out to out, of R. C. beams.

E =modulus of elasticity for any material.

h =any height in inches.

I =moment of inertia of any cross section.

k =radius of gyration of any cross section $= \sqrt{\frac{I}{A}}$

L, l,=span of any beam, etc., between centres of supports in feet and inches respectively.

m=a constant in the formula for strength of beams.

n=distance in R. C. beams from the upper surface of the concrete in compression to the neutral axis.

N=number of rivets at each end of a member of a truss : number of stirrups in the half span of a R. C. beam. Notation—(*contd.*).

O=total perimeter in inches of the tensile reinforcing bars in a R. C. beam.

p=percentage of steel reinforcement in R. C. beams : subscript letters as for A.

q=a constant in the formula for deflection of beams.

r=extreme fibre stress per sq. inch in beams subjected to cross bending : any radius in inches : pitch of helix in R. C. columns. Safe resistance per unit area of soils.

r_b=bearing stress per sq. inch.

S, s,=total amount and intensity per sq. inch respectively of shearing stress.

T, t,=total amount and intensity per sq. inch respectively of tensile stress.

t_p=thickness in inches of steel plates.

V=deflection in inches of any beam, etc.

W=total weight supported by any beam, etc.

w=weight per sq. foot or per foot run supported by any beam, etc.

y=distance from the neutral axis to the extreme fibre in any cross-section.

θ=angle that any beam, etc., makes with the horizon.

NOTE.—R. C. = r inforced concrete

TABLE 1.

Weights of building materials.

Material.	lbs. per cub. ft.	Material.	lbs. per sq. ft.
Clay	130	Corrugated iron 24 G .	$1\frac{1}{2}$
Loam	110	Corrugated iron 22 G .	2
Sand	25	Galvanised iron 24 G on 1 inch boarding.	5
Rammed earth . .	100	Mangalore tiles and battens.	10
Brickwork, burnt bricks .	120	Single Allahabad tiles and battens.	17
,, sun dried bricks	100	Double Allahabad tiles and battens	34
Stone masonry. . .	156	Single country tiles including frames.	14
Lime concrete . . .	115	Double country tiles including frames.	24
Cement concrete . .	130 to 150	Lime or mud plaster ceiling on wire netting.	7
Reinforced concrete . .	150	Eternit sheets or tiles $\frac{3}{16}$″	$2\frac{1}{2}$
Lime plaster . . .	106	Venesta or pine ceiling .	2
Lime mortar . . .	109	9″ thatch and frames .	10
Shingle	90	6″ thatch and frames .	$6\frac{1}{2}$
		Single Smith's tiling .	14
		Double Smith's tiling .	29

TABLE 2.

Strength and weight of timber.

Timber.	Weight per cubic foot lbs.	Safe strength lbs. per square inch. c. Crushing.	t. Tensile.	Formulæ for Transverse strength	Deflection
Teak (Tectona grandis)	53	1,210	1,353	$bd^2 = \frac{WL}{165}$	$bd^3 = \frac{WL^3}{215}$
Sal (Shorea robusta)	62	1 210	1,210	,, $= \frac{WL}{175}$	,, $= \frac{WL^3}{220}$
Deodar (Cedrus deodara)	40	700	700	,, $= \frac{WL}{115}$	,, $= \frac{WL^3}{170}$
Kail (Pinus excelsa)	32	700	700	,, $= \frac{WL}{115}$	,, $= \frac{WL^3}{170}$
Honnay (Pterocarpus marsupium)	56	..	1,800	,, $= \frac{WL}{210}$	,, $= \frac{WL^3}{220}$
Oregon pine (Abies douglasii)	34	1,200	700	,, $= \frac{WL}{100}$	,, $= \frac{WL^3}{180}$
Red pine (Pinus sylvestris)	36	800	1,400	,, $= \frac{WL}{130}$	,, $= \frac{WL^3}{245}$
Jarrah (Eucalyptus marginata)	55	6[illegible]0	1,100	,, $= \frac{WL}{150}$	,, $= \frac{WL^3}{185}$

NOTE.—The formulæ in the last two columns only refer to rectangular beams, uniformly loaded and supported. For other conditions see table 3. For round beams, read d^3 and d^4 for bd^2 and bd^3 respectively and multiply the right hand side of either equation by 1·7.

The deflection formula allows for a maximum deflection of $\frac{L}{30}$. For maximum deflection of $\frac{L}{40}$, multiply the right hand side of the equation by $\frac{4}{3}$. See page 72.

TABLE 3.

Bending moment and deflection constants for beams under transverse stress.

Condition of ends.	Nature of load.	Multiply right hand side of strength formula by	Multiply right hand side of deflection formula by
Both ends supported . . .	Distributed	1	1
Do. . . .	Concentrated at centre . .	2	1·6
One end fixed, one end free . .	Distributed	4	9·6
Do. . .	Concentrated at the free end .	8	25 6
One end fixed, one end supported	Distributed	1	·4
Do. .	Concentrated at centre . .	$1\frac{1}{2}$	·71
Both ends fixed . . .	Distributed	$\frac{2}{3}$	·2
Do.	Concentrated at centre . .	1	·4
Supported and continuous over 2 equal spans.	Distributed	1	·4

TABLE 4.

Trigonometrical functions for various angles of slope.

Slope.	Angle.	Sine.	Cosine.	Secant.	Cosecant.
1 in 1	45° 0′	·707	·707	1·414	1·414
2 in 3	33° 41′	·555	·832	1·202	1·803
1 in 2	26° 34′	·447	·894	1·118	2·236
1 in $2\frac{1}{2}$	21° 48′	·371	·928	1·077	2·693
1 in 3	18° 26′	·316	·949	1·054	3·162

D² **Values of bd²** B D²

Depth D	B BREADTH. 1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾	6
1	1·0	1·2	1·5	1·7	2·0	2·2	2·5	2·7	3·0	3·2	3·5	3·7	4·0	4·2	4·5	4·7	5·0	5·2	5·5	5·7	6·0
1¼	1·6	2·0	2·3	2·7	3·1	3·5	3·9	4·3	4·7	5·1	5·5	5·9	6·2	6·6	7·0	7·4	7·8	8·2	8·6	9·0	9·4
1½	2·2	2·8	3·4	3·9	4·5	5·1	5·6	6·2	6·7	7·3	7·9	8·4	9·0	9·6	10·1	10·7	11·2	11·8	12·4	12·9	13·5
1¾	3·1	3·8	4·6	5·4	6·1	6·9	7·7	8·4	9·2	10·0	10·7	11·5	12·3	13·0	13·8	14·6	15·3	16·1	16·8	17·6	18·4
2	4·0	5·0	6·0	7·0	8·0	9·0	10·0	11·0	12·0	13·0	14·0	15·0	16·0	17·0	18·0	19·0	20·0	21·0	22·0	23·0	24·0
2¼	5·1	6·3	7·6	8·9	10·1	11·4	12·7	13·9	15·2	16·2	17·7	19·0	20·2	21·5	22·8	24·0	25·3	26·6	27·8	29·1	30·4
2½	6·2	7·8	9·4	10·9	12·5	14·1	15·6	17·2	18·7	20·3	21·9	23·4	25·0	26·6	28·1	29·7	31·2	32·8	34·4	35·9	37·5
2¾	7·6	9·5	11·3	13·2	15·1	17·0	18·9	20·8	22·7	24·6	26·5	28·4	30·2	32·1	34·0	35·9	37·8	39·7	41·6	43·5	45·4
3	9·0	11·2	13·5	15·7	18·0	20·2	22·5	24·7	27·0	29·2	31·5	33·7	36·0	38·2	40·5	42·7	45·0	47·2	49·5	51·7	54·0
3¼	10·6	13·2	15·8	18·5	21·1	23·8	26·4	29·0	31·7	34·3	37·0	39·6	42·2	44·9	47·5	50·2	52·8	55·5	58·1	60·7	63·4
3½	12·2	15·3	18·4	21·4	24·5	27·6	30·6	33·7	36·7	39·8	42·9	45·9	49·0	52·1	55·1	58·2	61·2	64·3	67·4	70·4	73·5
3¾	14·1	17·6	21·1	24·6	28·1	31·6	35·2	38·7	42·2	45·7	49·2	52·7	56·2	59·8	63·3	66·8	70·3	73·8	77·3	80·9	84·4
4	16·0	20·0	24·0	28·0	32·0	36·0	40·0	44·0	48·0	52·0	56·0	60·0	64·0	68·0	72·0	76·0	80·0	84·0	88·0	92·0	96·0
4¼	18·1	22·6	27·1	31·6	36·1	40·6	45·2	49·7	54·2	58·7	63·2	67·0	72·2	76·8	81·3	85·8	90·3	94·8	99·3	104	108
4½	20·2	25·3	30·4	35·4	40·5	45·6	50·6	55·7	60·7	65·8	70·9	75·9	81·0	86·1	91·1	96·2	101	106	111	116	121
4¾	22·6	28·2	33·8	39·5	45·1	50·8	56·4	62·0	67·7	73·3	79·0	84·6	90·2	95·9	102	107	113	118	124	130	135
5	25·0	31·2	37·5	43·7	50·0	56·2	62·5	68·7	75·0	81·2	87·5	93·7	100	106	112	119	125	131	137	144	150
5¼	27·6	34·5	41·3	48·2	55·1	62·0	68·9	75·8	82·7	89·6	96·5	103	110	117	124	131	138	145	152	158	165
5½	30·2	37·[illegible]	45·4	52·9	60·5	68·1	75·6	83·2	90·7	98·3	106	113	121	129	136	144	151	159	166	174	181
5¾	33·1	41·3	49·6	57·9	66·1	74·4	82·7	90·9	99·2	107	116	124	132	141	149	157	165	174	182	190	198
6	36·0	45·0	54·0	63·0	72·0	81·0	90·0	99·0	108	117	126	135	144	153	162	171	180	189	198	207	216
6¼	39·1	48·8	58·6	68·4	78·1	87·9	97·7	107	117	127	137	146	156	166	176	186	195	205	215	225	234
6½	42·2	52·8	63·4	73·9	84·5	95·1	106	116	127	137	148	158	169	180	190	201	211	222	232	243	253
6¾	45·6	57·0	68·3	79·7	91·1	103	114	125	137	148	159	171	182	194	205	216	228	239	251	262	273
7	49·0	61·2	73·5	85·7	98·0	110	122	135	147	159	171	184	196	208	220	233	245	257	269	282	294
7¼	52·6	65·7	78·9	92·0	105	118	131	145	158	171	184	197	210	223	237	250	263	276	289	302	315
7½	56·2	70·3	84·4	98·4	112	127	141	155	169	183	197	211	225	239	253	267	281	295	309	323	337
7¾	60·1	75·1	90·1	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	360
8	64·0	80·0	96·0	112	128	144	160	176	192	208	224	240	256	272	288	304	320	336	352	368	384
8¼	68·1	85·1	102	119	136	153	170	187	204	221	238	255	272	289	306	323	340	357	374	391	408
8½	72·2	90·3	108	126	144	163	181	199	217	235	253	271	289	307	325	343	361	379	397	415	433
8¾	76·6	95·7	115	134	153	172	191	211	230	249	268	287	306	325	345	364	383	402	421	440	459
9	81·0	101	121	142	162	182	202	223	243	263	283	304	324	344	364	385	405	425	445	466	486
9¼	85·6	107	128	150	171	193	214	235	257	278	299	321	342	364	385	406	428	449	470	492	513
9½	90·2	113	135	158	180	203	226	248	271	293	316	338	361	384	406	429	451	474	496	519	541
9¾	95·1	119	142	166	190	214	238	261	285	309	333	356	380	404	428	452	475	499	523	547	570
10	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600
11	121	151	181	212	242	272	302	333	363	393	423	454	484	514	544	575	605	635	665	696	726
12	144	180	216	252	288	324	360	396	432	468	504	540	576	612	648	684	720	756	792	828	864

NOTE.—The figures immediately above the upper stepped line give d², those immediately above the lower stepped lines give bd² for a proportion of 1 to 2 and 1 to 3 for b to d.

TABLE 6.
Values of bd.³

B D³ | B D³

Depth. D	B BREADTH. 1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾	6
1	1·0	1·2	1·5	1·7	2·0	2·2	2·5	2·7	3·0	3·2	3·5	3·7	4·0	4·2	4·5	4·7	5·0	5·2	5·5	5·7	6·0
1¼	2·0	2·4	2·9	3·4	3·9	4·4	4·9	5·4	5·9	6·3	6·8	7·3	7·8	8·3	8·8	9·3	9·8	10·3	10·7	11·2	11·7
1½	3·4	4·2	5·1	5·9	6·7	7·6	8·4	9·3	10·1	11·0	11·8	12·7	13·5	14·3	15·2	16·0	16·9	17·7	18·6	19·4	20·2
1¾	5·4	6·7	8·0	9·4	10·7	12·1	13·4	14·7	16·1	17·4	18·8	20·1	21·4	22·8	24·1	25·5	26·8	28·1	29·5	30·8	32·2
2	8·0	10·0	12·0	14·0	16·0	18·0	20·0	22·0	24·0	26·0	28·0	30·0	32·0	34·0	36·0	38·0	40·0	42·0	44·0	46·0	48·0
2¼	11·4	14·2	17·1	19·9	22·8	25·6	28·5	31·3	34·2	37·0	39·9	42·7	45·6	49·4	51·3	54	57·0	59·8	62·6	65·5	68·3
2½	15·6	19·5	23·4	27·3	31·2	35·2	39·1	43·0	46·9	50·8	54·7	58·6	62·5	66·4	70·3	74·2	78·1	82·0	85·9	89·8	93·7
2¾	20·8	26·0	31·2	36·4	41·6	46·8	52·0	57·2	62·4	67·6	72·8	78·0	83·2	88·4	93·6	98·8	104	109	114	120	125
3	27·0	33·7	40·5	47·2	54·0	60·7	67·5	74·2	81·0	87·7	94·5	101	108	115	121	128	135	142	148	155	162
3¼	34·3	42·9	51·5	60·1	68·7	77·2	85·8	94·4	103	112	120	129	137	146	154	163	172	180	189	197	206
3½	42·9	53·6	64·3	75·0	85·8	96·5	107	118	129	139	150	161	171	182	193	204	214	225	236	247	257
3¾	52·7	65·9	79·1	92·3	105	119	132	145	158	171	185	198	211	224	237	250	264	277	290	303	316
4	64·0	80·0	96·0	112	128	144	160	176	192	208	224	240	256	272	288	304	320	336	352	368	384
4¼	76·8	96·0	115	134	154	173	192	211	230	249	269	288	307	326	345	365	384	403	422	441	461
4½	91·1	114	137	159	182	205	228	251	273	296	319	342	364	387	410	433	456	478	501	524	547
4¾	107	134	161	188	214	241	268	295	322	348	375	402	429	455	482	509	536	563	589	616	643
5	125	156	187	219	250	281	312	344	375	406	437	469	500	531	562	594	625	656	687	719	750
5¼	145	181	217	253	289	326	362	398	434	470	506	543	579	615	651	687	724	760	796	832	868
5½	166	208	250	291	333	374	416	458	499	541	582	624	665	707	749	790	832	873	915	957	998
5¾	190	238	285	333	380	428	475	523	570	618	665	713	760	808	855	903	951	998	1046	1093	1141
6	216	270	324	378	432	486	540	594	648	702	756	810	864	918	972	1026	1080	1134	1188	1242	1296
6¼	244	305	366	427	488	549	610	671	732	793	855	916	977	1038	1099	1160	1221	1282	1343	1404	1465
6½	275	343	412	481	549	618	687	755	824	893	961	1030	1098	1167	1236	1304	1373	1442	1510	1579	1648
6¾	308	384	461	538	615	692	769	846	923	1000	1076	1153	1230	1307	1384	1461	1538	1615	1692	1768	1845
7	343	429	514	600	686	772	857	943	1029	1115	1200	1286	1372	1458	1543	1629	1715	1801	1886	1972	2058
7¼	381	476	572	667	762	857	953	1048	1143	1238	1334	1429	1524	1620	1715	1810	1905	2001	2096	2191	2286
7½	422	527	633	738	844	949	1055	1160	1266	1371	1477	1582	1687	1793	1898	2004	2109	2215	2320	2426	2531
7¾	465	582	698	815	931	1047	1164	1280	1396	1513	1629	1746	1862	1978	2095	2211	2327	2444	2560	2677	2793
8	512	640	768	896	1024	1152	1280	1408	1536	1664	1792	1920	2048	2176	2304	2432	2560	2688	2816	2944	3072
8¼	562	702	842	983	1123	1263	1404	1544	1685	1825	1965	2106	2246	2386	2527	2667	2808	2948	3088	3229	3369
8½	614	768	921	1075	1228	1382	1535	1689	1842	1996	2149	2303	2456	2610	2763	2917	3071	3224	3378	3531	3685
8¾	670	837	1005	1172	1340	1507	1675	1842	2010	2177	2345	2512	2680	2847	3015	3182	3350	3517	3685	3852	4020
9	729	911	1093	1276	1458	1640	1822	2005	2187	2369	2551	2734	2916	3098	3280	3463	3645	3827	4009	4192	4374
9¼	791	989	1187	1385	1583	1781	1979	2176	2374	2572	2770	2968	3166	3364	3562	3759	3957	4155	4353	4551	4749
9½	857	1072	1286	1500	1715	1929	2143	2358	2572	2786	3001	3215	3429	3644	3858	4073	4289	4501	4716	4930	5144
9¾	927	1159	1390	1622	1854	2085	2317	2549	2781	3012	3244	3476	3707	3939	4171	4403	4634	4866	5098	5329	5561
10	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000	4250	4500	4750	5000	5250	5500	5750	6000
11	1331	1664	1997	2329	2662	2995	3328	3660	3993	4326	4659	4991	5324	5657	5990	6322	6655	6988	7321	7653	7896
12	1728	2160	2592	3024	3456	3888	4320	4752	5184	5616	6048	6480	6912	7344	7776	8208	8640	9072	9504	9936	10368

NOTE.—The figures immediately above the upper stepped line give d⁴ : those immediately above the lower stepped lines give bd³ for proportions of 1 to 2 and 1 to 3 for b to d.

TABLE 7.

Safe stress in tons per square inch in columns of cast iron, wrought iron and steel.

$\frac{l}{k}$	Cast iron.		Wrought iron.		Steel.	
	Ends rounded.	Ends fixed.	Ends rounded.	Ends fixed.	Ends rounded.	Ends fixed.
10	8·63	8·85	4·00	4·00	5·33	5·34
15	8·41	8·76	3·98	4·00	5·26	5·31
20	8·07	8·65	3·92	3·99	5·20	5·29
25	7·58	8·46	3·88	3·98	5·13	5·24
30	6·98	8·21	3·80	3·95	5·02	5·20
35	6·32	7·91	3·72	3·92	4·90	5·15
40	5·68	7·56	3·64	3·89	4·76	5·09
45	5·02	7·19	3·54	3·86	4·58	5·03
50	4·43	6·82	3·44	3·82	4·40	4·98
55	3·84	6·46	3·31	3·78	4·22	4·92
60	3·35	6·10	3·17	3·73	4·02	4·83
65	2·92	5·75	3·01	3·68	3·80	4·75
70	2·57	5·39	2·90	3·63	3·59	4·67
75	2·23	5·02	2·76	3·55	3·37	4·56
80	1·96	4·68	2·60	3·48	3·15	4·45
85	1·74	4·33	2·46	3·40	2·96	4·35
90	1·56	4·00	2·33	3·32	2·77	4·25
95	1·42	3·66	2·18	3·22	2·56	4·13
100	1·29	3·35	2·03	3·17	2·40	4·00
105	1·17	3·07	1·92	3·08	2·24	3·88
110	1·07	2·80	1·79	3·00	2·08	3·74
115	0·99	2·57	1·67	2·91	1·95	3·61
120	0·93	2·37	1·57	2·82	1·83	3·46
125	0·86	2·19	1·47	2·74	1·71	3·32
130	0·80	2·03	1·39	2·66	1·61	3·21
135	0·75	1·90	1·32	2·58	1·50	3·09
140	0·70	1·78	1·24	2·48	1·42	2·96
145	0·66	1·66	1·17	2·40	1·36	2·85
150	0·61	1·56	1·10	2·32	1·28	2·72

NOTE.—The constants in the formula from which these results have been obtained have the values given in Claxton Fidler's book 'A practical treatise on Bridge Construction (page 169 *et seq.*) 2nd edition, with a factor of safety of 4.

TABLE 8.

Safe load for wooden struts in lbs. per sq. inch.

$\frac{l}{b}$	Safe stress. Sal or Teak. A	Safe stress. Sal or Teak. B	Safe stress. Deodar or Kail. A	Safe stress. Deodar or Kail. B	$\frac{l}{b}$	Safe stress. Sal or Teak. A	Safe stress. Sal or Teak. B	Safe stress. Deodar or Kail. A	Safe stress. Deodar or Kail. B
9	1070	983	650	596	35	280	164	200	123
10	1042	925	630	570	36	266	155	192	116
11	1012	865	609	537	37	252	147	184	110
12	980	806	588	506	38	238	140	176	104
13	936	749	567	476	39	224	132	168	99
14	892	69[illegible]	546	448	40	210	125	160	94
5	848	642	525	422	41	204	119	154	90
16	805	592	504	398	42	198	113	148	86
17	768	546	483	375	43	192	107	142	83
18	731	504	462	352	44	186	102	136	80
19	694	465	441	329	45	180	97	130	77
20	657	429	420	307	46	174	93	126	74
21	620	399	404	286	47	168	89	122	71
22	583	371	388	267	48	162	85	118	68
23	546	345	372	250	49	156	82	114	64
24	510	321	356	234	50	150	79	110	61
25	475	300	340	219	51	144	76	108	59
26	440	280	324	205	52	138	73	102	58
27	420	261	308	191	53	132	70	98	56
28	401	243	292	180	54	126	68	94	54
29	382	226	276	169	55	120	66	90	52
30	363	212	260	160	56	115	64	87	51
31	344	202	248	152	57	110	62	84	49
32	325	192	236	144	58	107	60	81	47
33	309	182	224	137	59	103	58	79	46
34	294	173	212	130	60	100	56	77	45

A = One end rounded, one end fixed : B = both ends rounded.

For round posts take $\frac{l}{b} = 1{\cdot}15 \times \frac{l}{d}$.

For ends fixed take $\frac{6}{10} \times \frac{l}{b}$ and use the figure given under B.

TABLE 9.

Safe loads in lbs. on principal rafters of wooden trusses.

Timber square in section. Calculated as half fixed. | **A=Sal or teak. B=Deodar or kail.**

Width inches	Timber	Unsupported length in feet. 3	3½	4	4½	5	5½	6	6½	7	7½	8
2	A	2,925	2,480	2,040	1,720	1,450	1 250	1,065	920	792	710	648
	B	1,848	1,616	1 424	1 232	1 040	896	768	672	592	520	472
2¼	A	4,080	3.580	3,080	2,580	2,160	1,865	1,645	1,430	1,255	1,100	981
	B	2,555	2.270	2,015	1.805	1,583	1,380	1,195	1,055	920	815	728
2½	A	5,480	4,830	4,230	3,700	3,185	2,760	2,425	2 100	1,870	1,692	1 456
	B	3,365	3,030	2,730	2,460	2,225	1,900	1 760	1,550	1,350	1,20[illegible]	1,080
2¾	A	7,050	6,380	5,690	5 060	4,470	3,860	3,300	2 950	2,650	2,370	2,120
	B	4,240	3,900	3,580	3 260	2,970	2,700	2,420	2 170	1,925	1,700	1,515
3	A	8,920	8,030	7 240	6,580	5,860	5,260	4,590	4,030	3,610	3,320	2,930
	B	5.300	4,920	4,500	4,150	3,800	3,490	3,200	2.900	2,630	2 370	2,125
3¼	A	10,700	9.900	9,000	8,300	7,500	6,860	6,120	5.450	4,740	4,350	3,930
	B	6,440	6,030	5,550	5,100	4.760	4,400	4,070	3,760	3,470	3.170	2,830
3½	A	12,700	11,900	11 050	10,250	9,310	8.500	7,810	7,040	6,250	5,600	5,050
	B	7,610	7,210	6,760	6,300	5,880	5 475	5.040	4,710	4,360	4,100	3,825
3¾	A	14,760	13,950	13.000	12,120	11,310	10,500	9,660	8,810	7,990	7,170	6.380
	B	8,960	8,500	8.080	7 560	7,090	6,610	6,145	5,700	5,375	4,950	4,640
4	A	17 120	16,300	15,300	14 400	13,500	12,600	11,700	10.800	9,930	9,030	8,170
	B	10,400	9,930	9,420	8,900	8,400	7,900	7,400	6,880	6,470	6,025	5,700
4¼	A	20,570	19,400	18,200	17,130	16,020	15,000	13,910	13,000	12,040	11,050	10,170
	B	12.180	11,600	10,890	10,300	9,790	9,280	8,760	8,240	7,700	7,250	6,860
4½	A	24,450	22,800	21,200	19,900	18,630	17,500	16,300	15,300	14,300	13,300	12,310
	B	14,180	13,450	12,650	12.000	11,320	10.800	10,200	9,030	9.060	8,500	8,050
4¾	A	27,300	25,600	24,000	22,600	21,450	20,300	19,000	17,800	16,700	15,700	14,670
	B	15,790	14,950	14,200	13,580	12,900	12,350	11,780	11,170	10,570	10,000	9,400
5	A	30,250	28,550	26,850	25,500	24,500	23,100	21,850	20.600	19,370	18,350	17,200
	B	17,500	16,700	15,930	15,320	14,700	14,120	13,450	12,800	12,200	11,520	10,800

T **TABLE 10.** T

Properties of steel tees and safe loads as struts when used as principals of trusses.

b × d × t	w lbs. per r. f.	A sq. in.	I max.	I/y max.	k min	SAFE LOAD AS A STRUT IN TONS: OVER A LENGTH OF 3′	4′	5′	6′	7′	8′
1½×1½×¼	2·35	·692	·135	·13	·312	1·91	1 33	..	..	..	..
1½×2 ×¼	2 79	·82	·307	23	·288	2 06	1 41	..	..	..	..
1¾×1¾×¼	2 79	·82	221	·18	·361	2 63	1 91	1·41	..	..	..
2 ×2 ×¼	3·22	·947	·337	24	·407	3·36	2·56	1 94	..	..	..
2¼×2¼×¼	3·64	1·071	·488	·3	457	4·11	3·28	2 5	2·06	..	..
2 ×2 ×5/16	3·93	1·157	·403	·29	·416	4·18	3·22	2·48	1·87	..	..
2½×2½×¼	4 07	1 197	·677	38	·502	4 86	3 97	3·18	2 5	2 02	..
2¼×2¼×5/16	4·46	1·312	·587	·37	·465	5·11	4 11	3 33	2 55	..	..
2 ×2 ×⅜	4 64	1 367	·469	·34	424	5 0	3·89	3 03	2·37	..	..
2½×2½×5/16	5·01	1 474	·823	·46	·512	6 1	5·08	4·01	3·23	2 59	..
2¼×2¼×⅜	5·28	1 554	·685	·44	·474	6·11	4 93	3 85	3 04	..	..
3 ×2½×5/16	5 54	1 63	·872	·47	·639	7·39	4·46	5·52	4·62	3·86	3·25
2½×2½×⅜	5·92	1·742	·959	·55	521	7·25	6 01	4·85	3·89	3·22	..
3 ×3 ×5/16	6·12	1 8	1·469	·66	·609	8 07	6·88	5·82	4·84	4·01	3 35
3 ×2½×⅜	6 56	1·929	1·015	·56	·65	8·8	7·72	6 67	5·57	4·7	3 94
3 ×3 ×⅜	7·21	2·121	1 708	·8	62	9·55	8·25	6·94	5·85	4·83	4 06
3 ×3 ×7/16	8 3	2 441	2 035	·91	·64	11·0	9·57	8 08	6 83	5 68	4·92
3 ×4 ×⅜	8 48	2·494	3 822	1·387	·571	12·1	10 79	9 17	7·61	6·2	5·6
3½×3½×⅜	8 49	2·496	2·768	1·1	·717	11·7	10·5	9 2	8·0	6·8	5·8
4 ×3 ×⅜	8 49	2·498	1·86	·83	·863	12 1	11 3	10 3	9·22	8·2	7·25
3 ×2½×½	8·52	2 506	1·275	·73	·665	11 5	10 2	8 77	7·42	6·23	5·3
3 ×3 ×½	9 38	2 76	2 165	1·04	·636	12 45	10·9	9·25	7 82	6 54	5·78
4 ×4 ×⅜	9 77	2 872	4 189	1·45	·814	13·8	12·8	11·5	10 2	8 95	7 75
5 ×3 ×⅜	9·78	2·875	1·973	·85	·828	13·9	12·9	11·65	10·35	9 2	7·9
3½×3½×7/16	9·78	2 878	3·155	1·27	·725	13·52	12·25	10 7	9 31	7·94	6·8
5 ×4 ×⅜	11·07	3 257	4·471	1·49	1·065	16·4	15·65	14·8	13·7	12·5	11·4
3½×3½×½	11·08	3·259	3 543	1·44	·733	15 35	13·95	12 2	10 62	9 1	7·8
6 ×3 ×⅜	11·08	3·26	2·062	·87	·795	15·65	14·4	13 0	11·37	9·9	8·55
4 ×3 ×½	11·08	3·262	2·365	1·08	·851	15·9	14·75	13·4	11·95	10·55	9 27
3 ×4 ×½	11·08	3·26	5 05	1·89	·6	14·45	12·4	10·46	8·63	7·17	5 94
6 ×4 ×⅜	12 36	3·634	4·7	1·52	1·137	18 4	17·7	16·8	15·75	14·55	13·35
4 ×4 ×½	12·78	3·758	5·402	1·9	·83	18·2	16 85	15·25	13·55	11·9	10 35
5 ×3 ×½	12·79	3·762	2·516	1·11	·818	18·2	16·75	15·05	13·4	11·75	10·2
5 ×4 ×½	14·51	4·268	5·772	1·96	1·084	21·5	20·6	19·45	18·05	16·5	15·12
6 ×3 ×½	14·53	4·272	2·635	1·14	·785	20·4	18·75	16·7	14·65	12·8	11·1
6 ×4 ×½	16·22	4·771	6·07	2·0	1·128	24 15	23·2	22·0	20 75	19·05	17·45

The safe loads are calculated for struts with one end rounded and one end fixed: to use the table or struts with both ends rounded, their length must be multiplied by 1½.

TABLE 11.

Properties of steel angles.

d × b × t	w lbs. per. r. f.	A sq. in.	I max.	I/y max.	k min	k min ⌐ ⌐	Safe load as astrut, in tons, over a length of: Single angle, ends rounded 2′	3′	4′	5′	Double angle, ends rounded 2′	3′	4′	5′	Double angle, ends half fixed. 3′	4′	5′	6′	7′	8′
1¼×1¼×3/16	1 47	·433	·058	·07	·24	..	1 04	·55	.	..	..	..	..	..	..	..	..	..	..	..
1½×1½×3/16	1·79	·526	·105	·1	·29	..	1 59	·91	56	.	..	..	..	..	..	..	..	..	..	..
1¼×1¼×¼	1·91	·561	·073	·09	·23	..	1 27	·66	..	..	..	..	.	..	..	..	..	..	..	..
1¾×1¾×3/16	2·11	·622	172	·14	·34	..	2·22	1 37	·88	·59	..	..	..	..	..	..	..	..	..	..
2 ×1½×3/16	2 11	·622	24	17	32	62	2 1	1 25	·8	..	6·0	5 1	4 06	3 12	5 6	4·84	4·1	3·41	2 84	2·38
1½×1½×¼	2 33	686	·134	·13	29	.	2 08	1·18	·73	..	..	..	..	..	..	..	..	..	..	..
2 ×2 ×3/16	2·43	715	26	·18	·39	·6	2 82	1 91	1 26	·87	6 81	5 76	4 51	3 44	6 34	5 45	4 58	3 79	3 15	2·61
2¼×2¼×3/16	2·75	809	·378	·23	·44	·68	3 42	2 48	1·71	1 19	7 92	6 92	5·75	4 57	7·45	6 64	5 74	4 9	4 12	3 51
1¾×1¾×¼	2·77	814	·22	·18	·34	..	2 91	1 8	1 15	·77	..	..	..	..	..	.	..	..	..	..
2 ×1½×¼	2·77	·814	·308	·23	·31	·62	2 65	1 56	·93	..	7 85	6·69	5 31	4 06	7·31	6·33	5 35	4·45	3·7	3·0
2 ×2 ×¼	3·19	·938	336	·24	·39	·6	3·7	2 49	1 65	1·14	8 92	7 51	5 9	4 5	8·3	7 12	6 0	4·98	4·1	3 41
2 ×1½×5/16	3 39	·997	·369	·28	·31	·61	3 25	1·91	1·2	..	9·55	8·1	6 41	4 87	8·88	7 68	6 46	5 38	4 46	3·73
2¼×2¼×¼	3·61	1 063	·489	·3	·44	·68	4 5	3 27	2 25	1 57	10 4	9 13	7 6	6 0	9·82	8·81	7·55	6.45	5.44	4.62
2½×2 ×¼	3·61	1 063	·636	·37	·42	·77	4·4	3·11	2·1	1·47	10·6	9·6	8·3	6·9	10·15	9·25	8 23	7 22	6·25	5 38
2 ×2 ×5/16	3·92	1·153	·401	·29	·38	·59	4·46	2 98	1 82	1 34	10 9	9·2	7 13	5 4	10 15	8 67	7·28	6·0	4·96	4·1
2½×2½×¼	4 04	1·187	·677	·38	·48	·76	5·22	4 0	2 85	2 03	11 8	10 7	9 2	7 67	11 3	10 25	9 14	7·97	6·88	5·85
3 ×2 ×¼	4·04	1·187	1·06	·52	·43	·87	4 96	3 55	2 42	1·7	12 0	11 2	10 0	8·6	11 6	10 85	9 85	8·8	7·85	6·98
2¼×2¼×5/16	4·45	1·309	·592	·37	·43	·67	5 48	3·91	2 67	1 87	12 8	11 1	9 24	7 29	12 0	10 67	9 25	7·83	6·5	5 61
2½×2 ×5/16	4·45	1 309	·77	·45	·42	·77	5 4	3 83	2 59	1 82	13 1	11 8	10 2	8 5	12·45	11·4	10·15	8·93	7·69	6 62
3 ×2½×¼	4 46	1·312	1·14	·54	·52	·93	5·95	4·75	3·49	2 55	13·4	12 5	11 3	10 1	12·95	12 15	11·35	10·13	9 2	8·07
2 ×2 ×⅜	4·62	1 36	·467	·34	·38	·59	5·29	3·51	2 28	1 58	12·9	10 8	8 41	6 37	11·95	10 2	8 54	7·07	5 9	4·89
3 ×3 ×¼	4·9	1·44	1·21	·56	·59	·92	6 8	5·72	4 45	3 36	14 8	13 8	12·5	10·9	14·25	13 4	12·3	11·06	10 02	8·93
2½×2½×5/16	4·98	1·464	·822	·46	·48	·75	6·48	4·95	3·52	2 51	14 6	13 1	11·2	9·21	13·9	12 6	11·1	9·7	8·37	7·19
2¼×2¼×⅜	5·26	1·547	·686	·44	·43	·67	6·47	4 62	3·16	2 21	15·0	13·1	10·9	8·6	14·15	12·6	10·85	9·25	7·73	6·61

TABLE 11—(*contd.*).

Properties of steel angles.

d × b × t	w lbs. per r. f.	A sq. in.	I max.	I/y max.	k min ┐	k min. ┐ ┌	Safe load as a strut, in tons, over a length of — Single angle : ends rounded 2′	3′	4′	5′	Double angle ends rounded 2′	3′	4′	5′	Double angle ends half fixed. 3′	4′	5′	6′	7′	8′
2½ × 2 × ⅜	5·26	1·547	·895	·53	·42	·76	6·4	4·53	3·05	2·15	15·4	13·9	12	9·58	14·7	13·4	11·8	10·4	9·0	7·7
2½ × 2½ × ⅜	5·89	1·733	·962	·55	·48	·75	7·61	5·83	4·15	2·96	17·2	15·5	13·3	10·9	16·5	14·9	13·2	11·7	9·9	8·5
3 × 2 × ⅜	5·89	1·733	1·5	·76	·42	·91	7·18	5·05	3·41	2·4	17·8	16·5	14·9	13·1	17·1	16·0	14·8	13·3	12·0	10·7
3½ × 2½ × 5/16	6·05	1·779	2·15	·9	·54	1·08	7·95	6·6	4·93	3·65	18·4	17·6	16·3	14·9	18·0	17·1	16·2	15·1	13·8	12·6
3 × 2½ × ⅜	6·53	1·921	1·62	·79	·52	·92	8·7	6·93	5·05	3·72	19·6	18·3	16·6	14·6	19·0	17·8	16·4	14·8	13·4	11·9
3½ × 3 × 5/16	6·58	1·934	2·27	·92	·62	1·08	9·3	7·92	6·3	4·81	20·0	19·1	17·8	16·2	19·6	18·7	17·6	16·4	15·0	13·7
3½ × 3½ × 5/16	7·11	2·091	2·39	·95	·68	1·07	10·2	8·95	7·41	5·9	21·6	20·6	19·2	17·5	21·1	20·2	19·1	17·7	16·1	14·7
4 × 3 × 5/16	7·11	2·091	3·31	1·2	·64	1·26	10·1	8·73	7·05	5·23	21·8	21·2	20·1	18·8	21·6	20·8	19·9	18·9	17·6	16·4
3 × 3 × ⅜	7·18	2·111	1·72	·81	·58	·9	9·96	8·32	6·4	4·77	21·5	20·1	18·1	15·8	20·8	19·5	17·9	16·1	14·5	12·7
3½ × 2½ × ⅜	7·18	2·111	2·52	1·07	·53	1·09	9·65	7·75	5·78	4·25	21·7	20·8	19·5	17·8	21·3	20·4	19·3	17·9	16·5	15·1
4 × 3½ × 5/16	7·64	2·246	3·46	1·22	·72	1·24	11·1	9·85	8·4	6·75	23·4	22·8	21·5	20·0	23·1	22·3	21·2	20·2	18·8	17·4
2½ × 2½ × ½	7·65	2·249	1·21	·71	·48	·73	9·9	7·58	5·39	3·84	22·2	19·8	16·9	13·7	21·1	19·1	16·8	14·6	12·5	10·6
3 × 2 ½	7·65	2·249	1·89	·98	·42	·92	9·3	6.55	4·43	3·11	23·0	21·5	19.4	17·0	22·3	20·8	19·2	17·2	15·6	14·3
3½ × 3 × ⅜	7·81	2·298	2·67	1·1	·62	1·08	11·0	9·41	7·47	5·71	23·7	22·7	21·1	19·3	23·2	22·2	21·0	19·5	17·8	16·3
5 × 3 × 5/16	8·17	2·402	6·14	1·84	·65	1·24	11·6	10·1	8·2	6·4	25·0	24·3	23·0	21·4	24·7	23·8	22·7	21·6	20·1	18·6
4 × 3 × ⅜	8·45	2·485	3·89	1·42	·64	1·25	12·0	10·4	8·4	6·48	25·9	25·1	23·8	22·2	25·5	24·7	23·6	22·4	20·9	19·4
3½ × 3½ × ⅜	8·45	2·485	2·8	1·12	·68	1·06	12·2	10·7	8·85	7·02	25·6	24·5	22·8	20·5	25·1	23·9	22·4	20·9	19·1	17·4
3 × 2½ × ½	8·5	2·499	2·05	1·02	·52	·91	11·3	9·0	6·63	4·85	25·5	23·8	21·4	18·8	24·6	23·1	21·2	19·2	17·2	15·3
4 × 3½ × ⅜	9·08	2·671	4·08	1·45	·72	1·24	13·2	11·7	9·95	8·05	27·8	27·0	25·5	23·8	27·4	26·4	25·3	24·0	22·4	20·7
3 × 3 × ½	9·36	2·752	2·19	1·05	·58	·89	13·0	10·8	8·38	6·22	28·0	26·1	23·4	20·3	27·0	25·3	23·2	20·8	18·5	16·1
3½ × 2½ × ½	9·36	2·752	3·2	1·39	·53	1·08	12·6	10·1	7·52	5·51	28·5	27·2	25·3	23·1	27·8	26·6	25·1	23·3	21·4	19·8
4 × 4 × ⅜	9·72	2·859	4·26	1·48	·78	1·22	14·2	13·0	11·4	9·4	29·8	28·9	27·4	25·4	29·4	28·3	27·0	25·3	23·8	22·0
5 × 3 × ⅜	9·72	2·859	7·24	2·18	·65	1·26	13·8	12·0	9·75	7·62	29·9	29·0	27·6	25·6	29·5	28·5	27·1	25·3	24·1	22·5
3½ × 3 × ½	10·2	3·001	3·4	1·42	·61	1·06	14·3	12·2	9·65	7·47	31·0	29·6	27·5	24·8	29·8	28·9	27·1	25·2	23·1	21·1

TABLE 11—(*concld.*).

Properties of steel angles.

d × b × t	w lbs. per r. f.	A sq. in.	I max.	I/y max	k min. ┐	k min. ┐ ┌	Safe load as a strut, in tons, over a length of . Single angle ends rounded 2′	3′	4′	5′	Double angle ends rounded 2′	3′	4′	5′	Double angle : ends half fixed. 3′	4′	5′	6′	7′	8′
5 × 3½ × ⅜	10·37	3·05	7·64	2·24	·75	1·49	15·1	13·6	11·7	9·6	31·9	31·4	30·3	29·0	31·7	30·9	29·9	28·8	27·6	26·2
5½ × 3½ × ⅜	11·0	3·236	9·93	2·68	·76	1·45	16·1	14·5	12·5	10·3	33·9	33·1	31·9	30·4	33·5	32·7	31·6	30·4	29·0	27·4
5 × 4 × ⅜	11·0	3·236	7·96	2·28	·85	1·57	16·4	15·0	13·4	11·5	34·0	33·3	32·4	31·1	33·7	33·0	32·1	30·8	29·7	28·4
6 × 3 × ⅜	11·0	3·236	12·0	3·09	·64	1·19	15·6	13·5	10·9	8·4	33·5	32·5	30·6	28·3	33·0	31·7	30·2	28·5	26·5	24·4
4 × 3 × ½	11·05	3·251	4·98	1·85	·63	1·24	15·7	13·4	10·7	8·28	33·9	32·9	31·1	29·0	33·4	32·2	30·8	29·2	27·2	25·2
3½ × 3½ × ½	11·05	3·251	3·57	1·46	·68	1·05	16·0	14·0	11·6	9·2	33·5	32·0	29·5	26·9	32·8	31·2	28·8	27·1	24·8	22·5
6 × 3½ × ⅜	11·64	3·424	12·65	3·17	·76	1·41	17·0	15·4	13·3	10·9	35·9	35·0	33·6	32·0	35·5	34·5	33·3	32·0	30·3	28·7
4 × 3½ × ½	11·9	3·499	5·23	1·89	·71	1·22	17·2	15·3	12·9	10·4	36·4	35·2	33·6	31·0	35·8	34·6	32·9	31·1	29·1	26·9
5 × 5 × ⅜	12·27	3·610	8·51	2·34	·98	1·53	18·5	17·5	16·0	14·3	38·0	37·1	36·0	34·5	37·6	36·7	35·6	34·4	33·0	31·3
6½ × 3½ × ⅜	12·27	3·610	15·73	3·68	·75	1·37	17·9	16·2	13·8	11·4	37·9	36·8	35·4	33·4	37·4	36·3	34·9	33·4	31·8	29·9
6 × 4 × ⅜	12·27	3·610	13·19	3·23	·87	1·64	18·3	17·0	15·3	13·1	38·0	37·4	36·4	35·1	37·7	37·0	36·1	34·9	33·7	32·3
4 × 4 × ½	12·75	3·749	5·46	1·93	·77	1·21	18·7	16·9	14·6	12·1	38·9	37·7	35·6	33·1	38·3	36·9	35·2	33·1	31·0	28·6
5 × 3 × ½	12·75	3·749	9·33	2·85	·64	1·29	18·1	15·6	12·6	9·7	39·0	37·8	36·1	33·8	38·4	37·3	35·7	34·0	32·0	29·8
5 × 3½ × ½	13·61	4·003	9·86	2·93	·75	1·52	19·4	17·9	15·4	12·6	42·0	41·2	39·9	38·3	41·6	40·7	39·5	38·1	36·7	34·8
5 × 4 × ½	14·46	4·252	10·3	2·09	·84	1·56	21·5	19·9	17·6	15·0	44·7	43·8	42·5	40·9	44·2	43·3	42·2	40·6	39·2	37·3
5½ × 3½ × ½	14·46	4·252	12·8	3·51	·75	1·48	21·1	19·0	16·3	13·4	44·6	43·7	42·3	40·3	44·2	43·1	41·7	40·2	38·3	36·4
6 × 3 × ½	14·46	4·252	15·5	4·05	·63	1·22	20·5	17·6	14·1	10·8	44·3	42·3	40·6	37·7	43·6	42·0	40·2	37·8	35·4	32·7
6 × 3½ × ½	15·31	4·502	16·4	4·16	·75	1·44	22·4	20·2	17·3	14·2	47·2	46·2	44·4	42·2	46·7	45·5	43·9	42·3	40·3	38.1
5 × 5 × ½	16·15	4·75	11·0	3·07	·98	1·52	24·4	22·9	21·0	18·8	49·8	48·9	47·3	45·3	49·4	48·2	46·9	45·1	43·4	41·2
6 × 4 × ½	16·15	4·75	17·1	4·23	·86	1·67	24·0	22·3	19·9	17·0	49·9	49·0	47·9	46·2	49·5	48·7	47·5	46·1	44·5	42·7
6½ × 3½ × ½	16·15	4·75	20·4	4·83	·75	1·44	23·6	21·3	18·2	15·0	49·7	48·7	46·8	44·5	49·3	47·9	46·7	44·4	42·5	40·2
7 × 3½ × ½	17·0	5·0	25·1	5·58	·74	1·42	24·8	22·3	19·0	15·6	52·4	51·2	49·3	46·8	51·8	50·0	48·7	46·7	44·5	42·0
6 × 6 × 7/16	17·21	5·062	17·3	3·97	1·18	1·85	26·2	25·3	23·9	22·1	53·5	53·0	52·0	50·2	53·3	52·6	51·4	50·3	48·8	47.1
6½ × 4½ × ½	17·84	5·248	22·2	5·02	·97	1·91	27·0	25·4	23·2	20·6	55·5	54·7	53·9	52·2	55·1	54·4	53·2	52·2	50·8	49·2

NOTE.—In the case of double angles it is assumed that the longer flanges are placed back to back, separated by ⅜" for angles up to 3½" leg, ½" for angles up to 5" × 5" and 6½" × 3½", ⅝" for any angles larger than this.

TABLE 12.

I Properties of standard rolled steel beams. I

d × b	w lbs. per r. f.	A sq. in.	I max.	I/y max.	k min.	d × b	w lbs. per r. f.	A sq. in.	I max.	I/y max.	k min.
3 × 1½	4	1·176	1 659	1·106	·324	12 × 5	32	9·41	220	36 66	1·01
4 × 1¾	5	1·47	3 668	1·834	·355	8 × 6	35	10 29	110·5	27 62	1 32
4½ × 1¾	6¼	1·912	6·73	2 833	37	10 × 6	42	12 35	211·5	42 3	1 36
3 × 3	8½	2·5	3 787	2 524	·71	15 × 5	42	12 35	428	57·06	·978
4 × 3	9½	2 794	7·52	3·76	·677	12 × 6	44	12·94	315·3	52·55	1 31
5 × 3	11	3 235	13·61	5·444	·672	14 × 6	46	13 53	440·5	62 92	1·26
6 × 3	12	3 53	20 21	6·736	·616	12 × 6	54	15·88	375 5	62·58	1 33
7 × 4	16	4·706	39 21	11·2	·851	14 × 6	57	16 76	532·9	76 12	1·29
5 × 4½	18	5·29	22 69	9·076	1·03	9 × 7	58	17 06	229 5	51	1 64
8 × 4	18	5 294	55 69	13 92	·822	15 × 6	59	17·35	628·9	83 85	1·27
6 × 4½	20	5 88	34 62	11 54	·959	16 × 6	62	18 23	725·7	90·71	1 21
9 × 4	21	6·176	81 1	18 02	·824	10 × 8	70	20 6	344·9	68·98	1·86
6 × 5	25	7 35	43·61	14 53	1 11	18 × 7	75	22 06	1149	127·6	1 46
8 × 5	28	8 24	89 32	22 33	1 11	20 × 7½	89	26 17	1670	167	1 54
10 × 5	30	8·82	145 6	29 12	1·05	24 × 7½	100	29 4	2654	221·2	1 5

TABLE 13.

Strength of steel rivets.

Number of rivets=stress in member in tons ÷ factor from table.

Diam. of rivet.	SHEARING 5 TONS.		BEARING 8 TONS THICKNESS OF PLATES IN INCHES.									
	Single.	Double.	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{7}{8}$
¼	4 07	2·03	2 0	..	..	.	..	..	..	..	..	..
⅜	1·81	·91	1 33	1·07	·89	..	..	..	..	..	..	..
½	1 04	·52	1 0	·8	·67	·57	·5	..	..	..	..	..
⅝	·65	·325	·8	·64	·53	·46	·4	36	·32	..	..	..
¾	·45	·225	·67	·53	·44	·38	·33	·3	·27	·24	·22	..
⅞	·333	·167	·57	·46	38	·33	·29	·25	·23	·21	·19	..
1	·255	·127	5	·4	33	·28	·25	·23	·2	·18	·17	·1

TABLE 14.

Constants for Fink trusses.

—		Number of panels in truss. c. = cambered: u. = uncambered. 4 c.	4 u.	6 c	6 u.	8 c.	8 u.	10 c.	10 u.	12 c.	12 u.	14 c.	14 u.
W =	w × L × D ×	8·4		·933		·98		1 008		1·027		1·04	
	+weight of purlins	..		..		..		..		..		..	
	+(weight of truss in lbs.) $L^2 \times D \times$.	·06		·067		·07		072		·073		·074	
$W_1 = w_1 \times L \times D \times$		42		·467		49		·504		·514		·52	
Maximum wind reaction.	(Ends fixed) $W_1 \times$ . .	·583		·62		·64		·65		·66		·66	
	(One end free) $W_1 \times$ . .	·683		71		·72		·73		·74		·74	
Principal	Length (unsupported = L × .	28		·187		·14		·112		·093		·08	
	Dead load stress = W × .	1·47	1 12	1·47	1 12	1 47	1·12	1·47	1·12	1·47	1·12	1·47	1·12
	Wind stress (Ends fixed) = W_1 ×	1 6	1·16	1·69	1 23	1 79	1·28	1·82	1·3	1·84	1·32	1·87	1·32
	Wind stress (One end free) = W_1 ×	1 67	1·16	1 77	1 23	1 86	1 28	1 87	1 3	1·9	1·32	1 9	1·32
Centre strut	Length (unsupported) = L × .	·1	14	·14	17	1	·14	·12	·155	·1	·14	·11	·15
	Dead load stress = W × .	·3	3	24	·21	·25	25	·18	·17	·24	·24	·14	·14
	Wind stress (Ends fixed) = W_1 ×	66	·66	·55	48	·58	·58	·39	·37	·54	·54	·33	·33
	Wind stress (One end free) = W_1 ×	·66	·66	55	·48	·58	·58	·39	·37	·54	·54	·33	·33
Side struts	Length (unsupported) = L ×	..	..	..	..	·05	·07	·04	·055	·07	·088	·06	·075
	Dead load stress = W × .	..	..	..	..	·13	·13	·1	·1	·12	·1	·1	·08
	Wind stress (Ends fixed) = W_1 × .	..	..	..	..	29	·29	·225	·225	·26	·22	·21	·19
	Wind stress (One end free) = W_1 ×	..	..	..	..	·29	·29	·225	·225	·26	·22	·21	·19
Heel tie	Length (unsupported) = L × .	·3	·313	3	313	15	156	·12	·125	·15	·156	·13	·135
	Dead load stress = W × .	1 325	1	1 325	1	1 325	1	1·325	1	1·325	1	1·325	1
	Wind stress (Ends fixed) = W_1 × .	1·71	1 31	1·8	1 38	1 9	1·43	1 04	1·47	1·95	1·48	1·98	1·48
	Wind stress (One end free) = W_1 ×	1 95	1·48	2 05	1 55	2 13	1·6	2 13	1·6	2·17	1·62	2·17	1·62
Upper tie	Length (unsupported) = L × .	·3	·313	3	313	·15	·156	·12	·125	·15	·156	·13	·135
	Dead load stress = W × .	·58	33	·65	·4	·68	·42	·7	·44	·71	·45	·74	·46
	Wind stress. (Ends fixed) = W_1 ×	1 09	74	1·26	·88	1·38	·98	1·42	·98	1 43	1	1·5	1·03
	Wind stress. (One end free) = W_1 ×	1·13	·74	1·3	·88	1·41	1 05	1·45	1·1	1·48	1	1·5	1·03
Centre tie	Length (unsupported) = L × .	·41	·37	·41	·37	·41	·37	·41	·37	·41	·37	·41	·37
	Dead load stress = W × .	·78	·67	·71	·59	·68	·58	·66	·56	·65	·55	·61	·535
	Wind stress. (Ends fixed) = W_1 × .	·65	·56	·58	·49	·56	·48	·54	·48	·54	·47	·49	44
	Wind stress. (One end free) = W_1 ×	·855	·74	·795	·66	·78	·65	·72	·63	·72	·63	·66	·59
Side ties	Length (unsupported) = L × .	..	..	..	..	·15	·156	·12	·125	·15	·156	·13	·135
	Dead load stress = W × .	..	..	..	..	·19	·15	·14	·1	·25	·19	·2	·15
	Wind stress. (Ends fixed) = W_1 × .	..	..	..	..	·43	·32	·32	·25	·53	·4	·46	·33
	Wind stress. (One end free) = W_1 ×	..	..	..	..	·43	·32	·32	·25	·53	·4	·46	·33

Notes on Table 14.

The constants given in table 14 apply only to symmetrical Fink trusses, evenly loaded at the joints.

W and W_1 are the total dead and wind loads supported by the truss; w and w_1 are the amounts of dead load (covering only) and wind pressure per square foot of roof surface.

The camber is obtained by making the perpendicular distance between the junction of the main ties and the centre of the principal equal to one-tenth of the span.

Forms of Fink trusses.

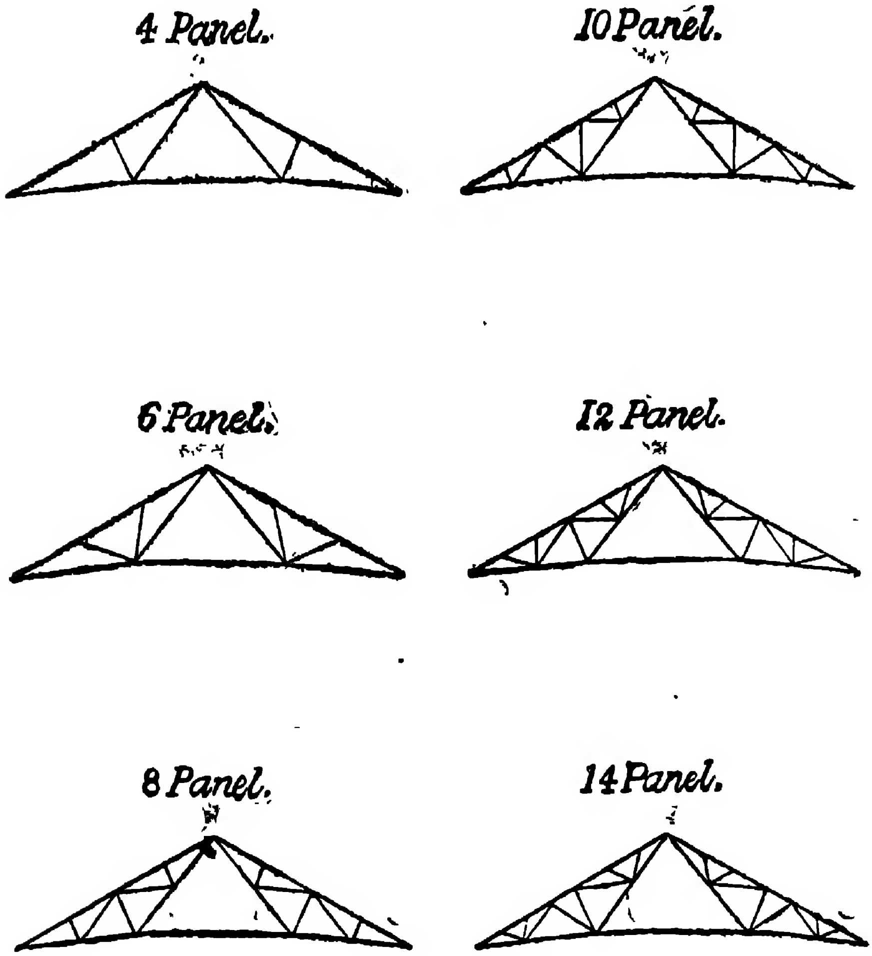


TABLE 15.

Strength and weight of round steel and wrought iron.

(6¼ tons per sq. in. for steel, 5 tons for wrought iron.)

Diameter.		⅛	3/16	¼	5/16	⅜	7/16	½	9/16	⅝	11/16	¾	⅞	1	1⅛	1¼	1⅜	1½
Area : sq. in.		·0123	·0276	·0491	·0767	·1104	·1503	·1963	·2485	·3068	3712	·4418	·6013	·7854	·994	1·227	1·485	1·767
Weight lbs. per r.f.	Steel	·042	·094	·167	261	·376	·511	·668	·845	1·04	1 26	1 5	2·04	2 67	3 38	4·17	5 05	6·01
	W. I.	·037	·083	·164	·256	·369	·502	·656	·831	1·025	1 24	1 48	2·01	2 62	3 32	4·09	4·96	5·9
Tensile strength tons. − threads	Steel	·042	·088	·169	·284	·425	·585	·756	1·02	1 27	1·6	1·9	2 64	3 46	4·36	5 69	6·44	8·13
	W. I.	·034	·07	·135	·228	·34	·468	·605	·815	1·02	1 28	1 52	2 11	2·77	3·49	4·55	5·15	6·5
+ threads	Steel	·077	·17	·31	·48	·69	·94	1·23	1 55	1·92	2 32	2·76	3·76	4·9	6 2	7 7	9·3	11·0
	W. I.	·062	·136	·248	·384	·55	·75	·99	1 24	1·54	1 86	2 21	3 01	3 92	4 96	6 16	7·34	8 8

NOTE.—Unless the end of the rod is upset before cutting the screw thread, the strength must be taken as that given for—threads.

TABLE 16.

Weight of hexagonal heads and nuts and round washers for wrought iron bolts.

Diameter of bolt.	¼	⅜	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½
Weight in lbs. of one head and one nut	·027	·069	·151	·279	·433	·641	·922	1·276	1·7	2·15	2·78
Weight in lbs. of one washer	·015	·018	·025	·04	·055	·075	·14	·175	·215	·26	·305
Thickness in inches of nut or head	·219	·328	·437	·547	·656	·766	·875	·984	1·094	1·203	1·312
Thickness in inches of washer	⅛	⅛	⅛	⅛	⅛	⅛	3/16	3/16	3/16	3/16	3/16
Add to grip for length, inches	·69	·91	1·12	1·34	1·56	1·78	2	2·22	2·44	2·66	2·87

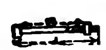


TABLE 17.

Weight of flat steel bars in lbs. per foot run.

Width in inches.			Thickness in inches.							
			1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2
..	..	1	·213	425	·638	·850	1 06	1 28	1 49	1 70
..	1¼	..	·266	531	·797	1 06	1 33	1 59	1·86	2·13
1½	..	..	·319	·638	·956	1 28	1 59	1 91	2 23	2·55
..	1¾	..	372	744	1 12	1 49	1 86	2 23	2·60	2 98
..	..	2	425	850	1 28	1 70	2 13	2 55	2·98	3 40
..	2¼	..	·478	·956	1 43	1·91	2 39	2 87	3 35	3·83
2½	..	..	531	1 06	1 59	2 13	2 66	3 19	3 72	4 25
..	2¾	..	584	1 17	1 75	2 34	2 92	3 51	4 09	4 68
..	..	3	638	1 28	1 91	2 55	3 19	3 83	4·46	5·10
..	3¼	..	691	1 33	2 07	2 76	3 45	4·14	4 83	5 53
3½	..	..	·744	1 49	2 23	2 98	3 72	4 46	5·21	5·95
..	3¾	..	797	1 59	2 39	3·19	3·98	4 78	5 58	6 38
..	..	4	850	1·70	2 55	3 40	4·25	5 10	5·95	6 80
..	4¼	..	·903	1 81	2 71	3·61	4·52	5 42	6·32	7·23
4½	..	..	·956	1 91	2 87	3 83	4·78	5·74	6·69	7·65
..	4¾	..	1 01	2 02	3 03	4 04	5 05	6 06	7·07	8·08
..	..	5	1·06	2·13	3·19	4 25	5 31	6 38	7·44	8.50
..	5¼	..	1·12	2·23	3·35	4 46	5·58	6·69	7·81	8·93
5½	..	..	1·17	2·34	3·51	4·68	5·84	7·01	8·18	9·35
..	5¾	..	1·22	2·44	3·67	4·89	6 11	7·33	8·55	9·78
..	..	6	1·28	2·55	3·83	5·10	6·38	7·65	8·93	10·20

EXAMPLES OF CALCULATIONS.

1. *Roof of a Follower's quarter.* — *References.*

Nature of roof. — Single Allahabad tiles on teak battens and rafters. Slope of roof 1 in 2, size of quarter 12′ long by 10′ wide: all walls 1½′. — Plate xxiii.

Load. — Bearing in mind that a very large number of such quarters will be required and that economy is therefore of importance, it is considered that, for so small a building, allowance for occasional load may be neglected and only the dead load due to the tiles taken into account.

Then vertical load = 17 lbs. sq. ft.
normal load = 15 lbs. sq. ft. — Table 1.

Arrangement of rafters. — The rafters may be supported on a ridgepole of steel or wood or they may be coupled by a tie joining their lower ends, thereby forming a collar beam truss and dispensing with a ridgepole. Each case will be worked out and their costs compared.

(*a*) With ridgepole.

Battens. — Span of rafter $= \frac{11\frac{1}{4}'}{2} \times \sec.\theta = \frac{11\frac{1}{4} \times 1{\cdot}118}{2}$ $= 6\frac{1}{4}'$ nearly. — Table 4.

Teak: $\frac{3}{4}'' \times 1''$. (1′ apart.) — Spacing of rafters $= \frac{\text{Span}}{4} + 6'' = \frac{6\frac{1}{4}}{4} + 6''$ $= 2\frac{1}{8}'$ nearly. — Para. 20.

The length of the room between centres of cross walls is 13½′ and the nearest higher spacing to the above will be 2·19′, giving 5 rafters per room.

Spacing of battens = 1′

$bd^2 = \frac{WL^2}{215} = \frac{(15 \times 1 \times 2{\cdot}19) \times 2{\cdot}19 \times 2{\cdot}19}{215}$ $= {\cdot}733$ or $\frac{3}{4}'' \times 1''$ — Para. 12. Table 6.

"See paragraph 20, pages 74 and 75."

Rafters. — Span 6¼′. Spacing 2·19′.

Teak: $1\frac{1}{2}'' \times 3''$. (2·19′ apart.) — $bd^2 = \frac{WL^2}{215} = \frac{(15 \times 2{\cdot}19 \times 6\frac{1}{4}) \times 6\frac{1}{4} \times 6\frac{1}{4}}{215}$ $= 37{\cdot}3$ or $1\frac{1}{2}'' \times 3''$. — Para. 12. Table 6.

Ridgepole. Teak: $3'' \times 7\frac{1}{2}''$ — Span 13½′. Width of roof supported = 6¼′.

or R. S. beam $4\frac{3}{4}'' \times 1\frac{3}{4}''$ @ 6½ lbs. — Load not reduced to normal. — Para. 16.

	1. *Roof of a Follower's quarter*—(contd.)	*References.*
Ridgepole—(contd.).	If of wood :	
	$bd^3 = \frac{WL^2}{215} = \frac{(17 \times 6\frac{1}{4} \times 13\frac{1}{8}) \times 13\frac{1}{8} \times 13\frac{1}{8}}{215}$	Para. 12
	$= 118$ or $3'' \times 7\frac{1}{4}''$.	Table 6.
	If of steel :	
	$I = \frac{WL^2}{17 \cdot 8} = \frac{(17 \times 6\frac{1}{4} \times 13\frac{1}{8}) \times 13\frac{1}{8} \times 13\frac{1}{8}}{17 \cdot 8 \times 2240}$ $= 6 \cdot 03$.	Para. 12.
	or $4\frac{3}{4}'' \times 1\frac{3}{4}''$ R.S. beam @ $6\frac{1}{2}$ lbs.	Table 12.
(*b*) Without ridgepole. *Battens.* Teak : $1'' \times 1\frac{1}{2}''$ (1′ apart)	Rafters may be spaced somewhat further apart, so as to avoid a forest of tiebeams : 3 rafters per room or a spacing of 3·28′ will do.	
	$bd^3 = \frac{WL^2}{215} = \frac{(15 \times 1 \times 3 \cdot 28) \times 3 \cdot 28 \times 3 \cdot 28}{215}$	Para. 12.
	$= 2 \cdot 46$ or $1'' \times 1\frac{1}{2}''$.	Table 6.
Rafters. Teak : $1\frac{1}{2}'' \times 3\frac{1}{2}''$ (3·28′ apart.)	Span $6\frac{1}{4}'$. Spacing 3·28′. Load not reduced to normal, as the rafter is under combined stress.	Para. 24.
	$bd^3 = \frac{WL^2}{215} = \frac{(17 \times 3 \cdot 28 \times 6\frac{1}{4}) \times 6\frac{1}{4} \times 6\frac{1}{4}}{215}$	Para. 12.
	$= 63 \cdot 3$ or $1\frac{1}{2}'' \times 3\frac{1}{2}''$	Table 6.
Tie. Steel hoop : $\frac{3}{4}'' \times \frac{1}{8}''$@ ·319 lbs.	Tension $= \frac{1}{2} W \cot \theta = \frac{1}{2} (wLD \sec. \theta) \cot \theta$.	Para. 23 (*a*) Table 4.
	$= \frac{1}{2} \times 17 \times 11\frac{1}{8} \times 3 \cdot 28 \times 1 \cdot 118 \times 2$ $= 693$ lbs.	
	A wooden tie will work out very small and a steel tie will be better.	
	$A = \frac{T}{t} = \frac{693}{6\frac{1}{4} \times 2240} = \cdot 0495$ or $\cdot 412'' \times \frac{1}{8}''$ net.	Para. 14. Para 2.
	To allow for screws a section $\frac{3}{4}'' \times \frac{1}{8}''$@ ·319 lbs. may be taken.	Table 17.

To compare the costs for one room in a block, neglecting wall plates, bolts, etc. :

(*a*) With ridgepole :

Battens $= 2 \times 9 \times 13\frac{1}{8} \times \frac{\frac{3}{4} \times 1}{144} \times 3 = 3 \cdot 69$

Rafters $= 2 \times 5 \times 7\frac{1}{4} \times \frac{1\frac{1}{2} \times 3}{144} \times 3 = 7 \cdot 27$

Wooden ridgepole.

$= 1 \times 13\frac{1}{8} \times \frac{3 \times 7\frac{1}{4}}{144} \times 3 = 5 \cdot 95$

Steel do. $= 1 \times 13\frac{1}{8} \times \frac{6\frac{1}{2}}{112} \times 8 = 6 \cdot 09$

Rs. 16·91 with wooden ridgepole.
Rs. 17·05 with steel ridgepole.

(*b*) Without ridgepole.

Battens $= 2 \times 9 \times 13\frac{1}{8} \times \frac{1 \times 1\frac{1}{2}}{144} \times 3 = 7 \cdot 38$

Rafters $= 2 \times 3 \times 7\frac{1}{4} \times \frac{1\frac{1}{2} \times 3\frac{1}{2}}{144} \times 3 = 5 \cdot 08$

Tie $= 3 \times 12 \times \frac{\cdot 319}{112} \times 14 = 1 \cdot 44$

Rs. 13·9

1. *Roof of a Follower's quarter*—(concld.) *References.*

Thus the collarbeam truss is more economical.

(NOTES.—If white-ants are prevalent an extra rafter per room may be given so as to avoid resting battens on a wallplate on the cross walls. For married soldiers' and Indian Officers' quarters, where a plaster ceiling is given under rafters 18″ apart, a ridgepole should be provided.)

2. *Roof of a Sergeants' Mess.*

Nature of building. The building consists of—

1 room 50′ × 24′.

2 rooms, each 30′ × 24′.

with a verandah 10′ wide in the clear all round. All walls $1\frac{1}{2}'$ thick.

A MAIN ROOF

Nature of roof. Double Allahabad tiles on Sal battens, rafters, purlins and kingpost trusses. Slope of roof 1 in 2. A horizontal ceiling of lime plaster on wire netting to be given under the tiebeam of the truss. — Plate xvi.

Loads.

Tiles	34 lbs.	Table 1.
Occasional load for 24′ span	19 „	Para. 8(*b*)
Ceiling	7 „	Table 1.
Occasional load on ceiling .	15 „	Para. 9.

Load for roof timbers = 53 lbs. vertical or 53 cos θ = 53 × ·894 = $47\frac{1}{2}$lbs. normal. — Table 4.

Load for ceiling timbers = 22 lbs. vertical.

Battens.

Sal : $1'' \times 1\frac{1}{2}''$. (1′ apart).

Span of rafters $= \frac{25\frac{1}{2}}{4} \times \sec\ \theta = \frac{25\frac{1}{2} \times 1{\cdot}118}{4} = 7\frac{1}{8}'$. — Table 4.

Spacing of rafters

$= \frac{L}{4} + 6'' = \frac{7\frac{1}{8}'}{4} + 6'' = 2{\cdot}28'$. — Para. 20.

Length of roof,

$= \frac{3}{4} + 1\frac{1}{2} + 50 + 1\frac{1}{2} + 30 + 1\frac{1}{2} + 30 + 1\frac{1}{2} + \frac{3}{4} = 117\frac{1}{2}'$.

Nearest higher rafter spacing to suit roof = 2·3′.

Spacing of battens = 1′.

$bd^3 = \frac{WL^2}{220} = \frac{(47\frac{1}{2} \times 1 \times 2{\cdot}3) \times 2{\cdot}3 \times 2{\cdot}3}{220}$ — Para. 12.

$= 2{\cdot}63$. — Table 6.

	2. *Roof of a Sergeants' Mess*—(contd.):	*References.*
Battens—(contd.).	Nearest suitable section $1'' \times 1\frac{1}{2}''$, where $bd^3 = 3{\cdot}4$: this may be used to its maximum permissible span.	
	$bd^3 = \frac{WL^3}{220}$ or $L^3 = \frac{3{\cdot}4 \times 220}{47\frac{1}{2}} = 15{\cdot}75$ and $L = 2{\cdot}5'$.	
	This spacing for rafters will suit the building.	
Rafters.	Span $= 7\frac{1}{8}'$. Spacing $= 2{\cdot}5'$.	Para. 12.
Sal : $2'' \times 4\frac{3}{4}''$ ($2\frac{1}{2}'$ apart).	$bd^3 = \frac{WL^3}{220} = \frac{(47\frac{1}{2} \times 2\frac{1}{2} \times 7\frac{1}{8}) \times 7\frac{1}{8} \times 7\frac{1}{8}}{220}$ $= 195$ or $2'' \times 4\frac{3}{4}''$.	Table 6.
Purlins.	Spacing of trusses $= \frac{\text{span} + 4\frac{1}{2}}{3} = \frac{25\frac{1}{2} + 4\frac{1}{2}}{3}$	Para. 22.
Sal : $3'' \times 6\frac{1}{2}''$.	$= 10'$.	
	It has to be remembered that the tie-beam is to carry a ceiling and, to avoid a very heavy section, a smaller spacing is desirable, say $7\frac{7}{8}'$ for the smaller rooms and $7{\cdot}36'$ for the larger room.	
	Width of roof supported $= 7\frac{1}{8}'$. Beams continuous.	Para 18.
	$bd^2 = \frac{WL}{175} = \frac{(47\frac{1}{2} \times 7\frac{1}{8} \times 7\frac{7}{8}) \times 7\frac{7}{8}}{175}$	Para. 11.
	$= 120$ or $3'' \times 6\frac{1}{2}''$.	Table 5.
Ridgepole. Sal : $2\frac{1}{2}'' \times 7\frac{1}{2}''$.	Conditions as for purlins, but load not reduced to normal.	Para. 16.
	$bd^2 = \frac{120 \times 53}{47\frac{1}{2}} = 134$ or $2\frac{1}{2}'' \times 7\frac{1}{2}''$.	Para. 11.
Principal Rafter.	Unsupported length of principal $= 7\frac{7}{8}'$.	Table 5.
Sal : $4'' \times 4''$ ($7\frac{7}{8}'$ apart).	$W = wLD \sec.\ \theta = 53 \times 25\frac{1}{2} \times 7\frac{7}{8} \times 1{\cdot}118$ $= 11900$ lbs.	Para. 23.
	$W_1 = w_1 LD = 7 \times 25\frac{1}{2} \times 7\frac{7}{8} = 1{,}400$ lbs.	
	$C = \frac{3}{8} W \operatorname{cosec.} \theta + \frac{1}{4} W_1 \operatorname{cosec} \theta$	Para. 23 (*b*).
	$= (\frac{3}{8} \times 11900 \times 2{\cdot}236) + (\frac{1}{4} \times 1400 \times 2{\cdot}236) = 9978 + 786 = 10{,}764$ lbs.	Table 4.
	A $4''$ square strut with ends half fixed takes about 9,800 lbs. over $7\frac{7}{8}'$: keeping the width at $4''$, the depth would have to be $\frac{4 \times 10{,}764}{9800} = 4\frac{1}{2}''$ nearly.	Table 9.
	Checking as an example :	
	$\frac{l}{b} = \frac{7\frac{7}{8} \times 12}{4} = 21\frac{5}{8}$ corresponding to a safe stress with ends half fixed of 597 lbs. per sq. in.	Table 8.
	$A = \frac{C}{c} = \frac{10{,}764}{597} = 18$ sq. in. or $4'' \times 4\frac{1}{2}''$.	Para. 13.
Struts : sal : $3'' \times 3''$. ***Kingpost*** : sal : $4'' \times 4''$.	The struts and kingpost need not be worked out ; struts may be $3'' \times 3''$; kingpost $4'' \times 4''$.	Para. 25.
Tiebeam.	As the tiebeam is under transverse	Para. 25
Sal : $4'' \times 8\frac{1}{4}''$.	stress, on account of the ceiling, it will be calculated for a deflection of $\frac{L}{40}$.	Para. 5.

2. *Roof of a Sergeants' Mess*—(contd.). *References.*

Tiebeam—(contd.).

Span$=\frac{25\frac{1}{2}}{2}=12\frac{3}{4}'$. Spacing$=7\frac{7}{8}'$.
Load$=22$ lbs. sq. ft.
$bd^2=\frac{WL^2}{220}\times\frac{4}{3}=\frac{(22\times7\frac{7}{8}\times12\frac{3}{4})\times12\frac{3}{4}\times12\frac{3}{4}\times4}{220\times3}$ — Para. 12.
$=2180$ or $4''\times8\frac{1}{4}''$. — Table 6.

To reduce the section of the tiebeam, it would be permissible to suspend it half way between the support and the kingpost by a rod from the principal just above the strut.

Heel joint.
Strap, ends forged $1\frac{1}{2}''\times\frac{1}{4}''$; bolt, $1\frac{1}{4}''$ diam.

Tension in tiebeam, $T=C\cos\theta=10{,}764\times\cdot894=9{,}623$ lbs. — Para. 23 (*b*).

$A=\frac{T}{2t}=\frac{9623}{2\times6\frac{1}{4}\times2240}=\cdot343$ sq. in. — Para. 27.
or $1\frac{1}{2}''\times\frac{1}{4}''$ if the ends are forged.

Diam. of bolt $=\frac{T}{b\times\frac{5c}{3}}=\frac{9623}{4\times\frac{5\times1210}{3}}$ — Table 1.
$=1\frac{1}{4}''$.

If the ends of the strap are not forged, its width must be $2\frac{3}{4}''$.

B. CEILING.

The ceiling joists, which must not be more than 18″ apart, may be supported in either of the following ways:—

(*a*) direct to the underside of the tiebeam, joists being parallel to the long walls.

(*b*) below crossbeams between tiebeams, joists being at right angles to longwalls.

(*c*) as in (*a*) and also attached to a beam slung by rods from the purlins and the ridgepole.

(*d*) as in (*b*) but attached to cross beams slung as in (*c*), no use being made of the tiebeam.

In cases (*b*) to (*d*) joists would have short spans and might well be treated as continuous. For cases (*c*) and (*d*) the purlins would have to be strengthened. With steel trusses (*d*) would be the best arrangement.

In the present instance (*a*) may be worked out.

Ceiling joists.
Sal: $1\frac{3}{4}''\times4''$

Span $7\frac{7}{8}'$. Spacing $1\frac{1}{2}'$. To be calculated as supported only for a deflection of $\frac{L}{40}$. Load 22 lbs. sq. ft. — Para. 5.

$bd^2=\frac{WL^2}{220}\times\frac{4}{3}=\frac{(22\times1\frac{1}{2}\times7\frac{7}{8})\times7\frac{7}{8}\times7\frac{7}{8}\times4}{220\times3}$ — Para. 11.
$=97\cdot6$ or $1\frac{3}{4}''\times4''$. — Table 5.

C VERANDAH — *2. Roof of a Sergeants' Mess—(contd.).* — *References.*

Nature of the roof.

Single Allahabad tiles on Sal battens and rafters and reinforced concrete bressummers, pillar caps and pillars: pillars to be not more than 10′ apart. Slope of roof 1 in 2.

(NOTE.—Battens and rafters of reinforced concrete have been used at certain stations: they have not, however, proved economical when compared with timber.)

Loads.

			References
Tiles	. . .	17 lbs.	Table 1.
Occasional load	.	15 lbs.	Para. 8 (*b*).

32 lbs. vertical or $28\frac{1}{2}$ lbs. normal per sq. foot.

Battens.
Sal : $1'' \times 1\frac{1}{2}''$ (1′ apart).

To avoid confusion, it will be as well to adopt the same section of batten as is being used for the main roof, *viz*, $1'' \times 1\frac{1}{2}''$, spacing 1′.

$bd^3 = \frac{WL^2}{220}$ or $3{\cdot}4 = \frac{(28\frac{1}{2} \times 1 \times L) \times L^2}{220}$, whence $L^3 = 26{\cdot}25$ and $L = 3'$. — Para. 12. Table 6.

Rafters.
Sal : $2\frac{3}{4}'' \times 6''$ (3′ apart).

Span $=(10' +$ half width of pillar) sec. $\theta = (10 + \frac{5}{16})\ 1{\cdot}118 = 11\frac{1}{2}'$ nearly.

Spacing $= 3'$.

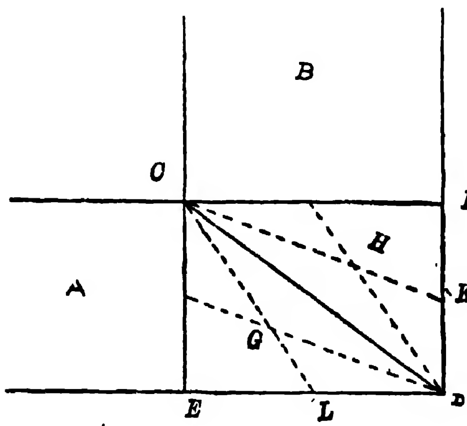
$bd^3 = \frac{WL^2}{220} = \frac{(28\frac{1}{2} \times 3 \times 11\frac{1}{2}) \times 11\frac{1}{2} \times 11\frac{1}{2}}{220}$
$= 592$ or $2\frac{3}{4}'' \times 6''$ — Para. 12. Table 6.

Hip rafter.
Sal : $3\frac{1}{2}'' \times 7''$.

A and B are two verandahs, CD the hip rafter and CF, EC the ordinary rafters on either side. Imagine CF, CE to represent the actual span on the rafter on the slope, in this case $11\frac{1}{2}'$ and ED, FD the length of each rafter in plan, in this case $10\frac{5}{16}'$. Then span of hip rafter

$= \sqrt{CE^2 + ED^2}$

$= \sqrt{(11\frac{1}{2})^2 + (10\frac{5}{16})^2} = 15{\cdot}35'$



2. *Roof of a Sergeants' Mess—(contd.).* — ***References.***

Hip rafter—(contd.).

Load on hip rafter = load on area CGDH, points H, G being found by joining C, D to the centre points of DF, etc.,

$= \frac{1}{3}$ of area CFDE $\times 28\frac{1}{2}$ lbs.

$= \frac{1}{3} \times \text{CE} \times \text{ED} \times 28\frac{1}{2}$

$= \frac{1}{3} \times 11\frac{1}{2} \times 10\frac{3}{16} \times 28\frac{1}{2}$

$= 1113$ lbs.

It is assumed that jack rafters are used to distribute the load between the hip rafter and the bressummers, otherwise the load on the hip rafter would be represented by the area CKDL.

$bd^3 = \frac{WL^2}{220} = \frac{1113 \times 15{\cdot}35 \times 15{\cdot}35}{220} = 1192$ or $8\frac{1}{2}'' \times 7''$. — Para. 12. Table 6.

Jack rafters.
Sal : $2\frac{3}{4}'' \times 6''$ (3′ apart).

Jack rafters may be of the same section as ordinary rafters: they are placed so that the span of the battens nowhere exceeds 3′.

Bressummer.
Reinforced concrete $4\frac{1}{2}'' \times 6''$.
2 bottom rods $\frac{1}{2}''$ diam.
2 top rods $\frac{5}{16}''$ diam.

If the pillar cap is made $3\frac{1}{2}'$ long, the span of the bressummer will be $(10' - 3\frac{1}{2}') = 6\frac{1}{2}'$ or say 7′ allowing for the bearing.

Width of roof supported $= \frac{1}{2}$ span of rafter + overhang $= \frac{11\frac{1}{2}}{2} + 1 = 6\frac{3}{4}'$.

W = Superincumbent load + weight of bressummer.

$= (28\frac{1}{2} \times 6\frac{3}{4} \times 7) + (7 \times \frac{4\frac{1}{2} \times 6}{144} \times 150)$ — Table 1.

$= 1347 + 197 = 1544$ lbs.

Assume a section $4\frac{1}{2}'' \times 6''$; d, the effective depth being taken as 5″. — Para. 44.

$bd^2 = \frac{WL}{m}$ or $m = \frac{1544 \times 7}{4\frac{1}{2} \times 5 \times 5} = 96$, corresponding to $1\frac{1}{2}$ per cent. tensile reinforcement, with $A_c = {\cdot}4$At. — Table 5.

At $= \frac{pbd}{100} = \frac{1\frac{1}{2} \times 4\frac{1}{2} \times 5}{100} = {\cdot}337$ sq. in. — Para. 43.
or say 2 rods $\frac{1}{2}''$ diam. $= 2 \times {\cdot}1963 = {\cdot}3926$ sq. in.

Ac $= \times {\cdot}4$ At $= {\cdot}4 \times {\cdot}337 = {\cdot}135$. — Table 15.

or say 2 rods $\frac{5}{16}''$ diam. $= 2 \times {\cdot}0767 = {\cdot}1534$. — Table 15.

2. Roof of a Sergeants' Mess—(contd.) ***References.***

Bressummer—(contd.).

Testing for shear
$s=\frac{\cdot 568(wL)}{bd} = \frac{\cdot 568 \times 1544}{4\frac{1}{2} \times 5} = 39$ lbs. sq. in., which the concrete can easily resist. Para. 54.

As the beam may be more or less fixed at the ends, 1 rod should be turned up at $\frac{3\frac{1}{2}}{4}=1\frac{7}{8}'$ from the end of the cap nad car riedalong the upper portion, so as to resist any possible negative bending moment. Para. 42.

Pillar caps.
Reinforced concrete $4\frac{1}{2}'' \times 5\frac{1}{2}''$.
2 bottom rods, $\frac{1}{2}''$ diam.
2 top rods, $\frac{1}{2}''$ diam.

Span $=\frac{3\frac{1}{2}}{2}=1\frac{3}{4}'$. Width of roof supported $=6\frac{3}{4}''$.

The cap is a cantilever carrying an end load as follows :—

$$\left.\begin{array}{l} \text{Superincumbent} = 28\frac{1}{2} \times 6\frac{3}{4} \times \frac{6\frac{1}{2}}{2} = 625 \\ \text{Weight of bressummer} \times \frac{6\frac{1}{2}}{2} \times \frac{4\frac{1}{2} \times 6}{144} \times \\ \quad 150 = 91 \end{array}\right\} \doteq 716 \text{ lbs.}$$

This is equivalent to a distributed load of $2 \times 716 = 1432$ lbs. There is also a distributed load on the cap, thus :—

$$\left.\begin{array}{l} \text{Superincumbent} = 28\frac{1}{2} \times 6\frac{3}{4} \times 1\frac{3}{4} = 337 \\ \text{Weight of bressummer} = 1\frac{3}{4} \times \frac{4\frac{1}{2} \times 6}{144} \\ \quad \times 150 = 49. \\ \text{Weight of cap} = 1\frac{3}{4} \times \frac{4\frac{1}{2} \times 5\frac{1}{2}}{144} \times 150 = 45 \end{array}\right\} 431 \text{ lbs.}$$

Total distributed load $= 1432 + 431 = 1863$ lbs.

Assuming a section $4\frac{1}{2}'' \times 5\frac{1}{2}''$, with d as $4\frac{1}{2}''$:

$bd^2 = \frac{WL}{m} \times 4$ or $m = \frac{1863 \times 1\frac{3}{4} \times 4}{4\frac{1}{2} \times 4\frac{1}{2} \times 4\frac{1}{2}} = 143$ Table 3.

corresponding to a tensile reinforcement of 2 per cent. with $A_c = A_t$. Para. 40. Table 5.

$A_t = \frac{pbd}{100} = \frac{2 \times 4\frac{1}{2} \times 4\frac{1}{2}}{100} = \cdot 404$ sq. in. or say 2 rods $\frac{1}{2}''$ diam. $= 2 \times \cdot 1963 = \cdot 3926$, top and bottom. Table 15.

Pillar.
Reinforced concrete $4\frac{1}{2}'' \times 4\frac{1}{2}''$ 4 rods, $\frac{1}{2}''$ diam.

$W = 2 \times$ load at end and on cap $= (2 \times 716) + (2 \times 421) = 1432 + 842 = 2274$ lbs.

Assume a section $4\frac{1}{2}'' \times 4\frac{1}{2}''$: then if the pillar from the base to the underside of the cap is 6′ long. $\frac{l}{b} = \frac{6 \times 12}{3\frac{1}{2}} = 20\frac{1}{2}$, and the column is a "long" one, but as pressure per sq. inch, $c = \frac{2274}{3\frac{1}{2} \times 3\frac{1}{2}} = 186$ is so small, special calculations are unnecessary. Para. 58. Para. 59.

2. *Roof of a Sergeants' Mess*—(concld.).

Pillar—(contd.).	Theoretically no reinforcement at all is needed, but four rods, each $\frac{1}{4}''$ diam., @ ·0491 lbs., should be provided, one at each corner. It will be seen that the effective area has been taken $3\frac{1}{2}'' \times 3\frac{1}{2}''$.	*References.*

3. *Roof of an Indian Infantry barrack.*

Nature of roof.	Single Mangalore tiles on deodar battens and rafters, and steel purlins and trusses. A lime plaster ceiling to be given below the rafters, which must not be spaced more than 18″ apart. Slope of roof 1 in 2. The building consists of 4 rooms, each $36' \times 20'$, with two rooms for havildars, each $12' \times 9'$, at one end. All walls 18″ wide.	Plate XX.
Loads.	Tiles 10, Occasional load 15, Ceiling 7	Table 1. Para. 8 (*b*).
	32 lbs. vertical or $28\frac{1}{2}$ lbs. normal per sq. ft.	Table 1.
	On battens 25 lbs. vertical or $22\frac{1}{3}$ lbs. normal per sq. ft.	
Battens. Deodar : $\frac{3}{4}'' \times 1''$.	Span $1\frac{1}{2}'$. Spacing $13\frac{3}{4}'' = 1{\cdot}145'$. $bd^3 = \frac{WL^2}{170} = \frac{(22\frac{1}{3} \times 1{\cdot}145 \times 1\frac{1}{2}) \times 1\frac{1}{2} \times 1\frac{1}{2}}{170}$	Para. 12. Table 6.
	$= {\cdot}51$ or $\frac{3}{4}'' \times 1''$ if good timber is available : if not the minimum permissible scantling.	
Rafters. Deodar : $1\frac{3}{4}'' \times 3\frac{1}{2}''$.	Span $= \frac{21\frac{1}{2}}{4}$ sec. $\theta = \frac{21\frac{1}{2} \times 1{\cdot}118}{4} = 6'$. Spacing $= 1\frac{1}{2}'$. Deflection not to exceed $\frac{L}{40}$ on account of the plaster ceiling.	Table 4. Para. 9.
	$bd^3 = \frac{WL^3}{170} \times \frac{4}{3} = \frac{(28\frac{1}{2} \times 1\frac{1}{2} \times 6) \times 6 \times 6 \times 4}{170 \times 3}$ $= 72{\cdot}3$ or $1\frac{3}{4}'' \times 3\frac{1}{2}''$.	Para. 12. Table 6.
Purlins and Ridgepole. R.S. $3'' \times 1\frac{1}{2}''$ @ 4 lbs.	It will be best perhaps to carry the purlins entirely on trusses from end wall to end wall, making no use of the cross walls, which can be entirely of sundried brickwork.	
	Spacing of trusses $= \frac{\text{Span}+36}{7} = \frac{20+36}{7} = 8'$.	Para. 22.
	Length of barrack between centres of end walls. $= \frac{3}{4}+36+1\frac{1}{2}+36+1\frac{1}{2}+36+1\frac{1}{2}+36+1\frac{1}{2}+12+\frac{3}{4} = 163\frac{1}{2}'$.	
	The nearest higher spacing to suit this length is $8{\cdot}18'$.	

3. *Roof of an Indian Infantry barrack*—(contd). *References.*

Purlins and Ridgepole—(contd).

Width of roof supported=6′. Beams continuous. Para. 18.

$\frac{I}{y}=\frac{WL}{5}=\frac{(28\frac{1}{4}\times 6\times 8{\cdot}18)\times 8{\cdot}18}{5\times 2240}=1{\cdot}022.$ Para. 11.

For the ridgepole, where the load is not reduced to normal. Table 12.

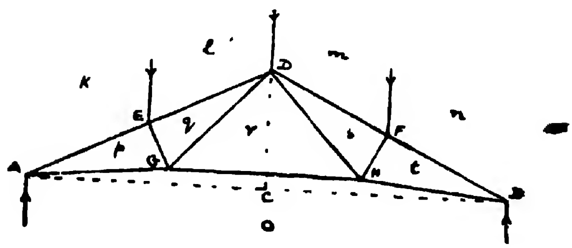
$\frac{I}{y}=\frac{1{\cdot}022\times 32}{28\frac{1}{4}}=1{\cdot}148.$

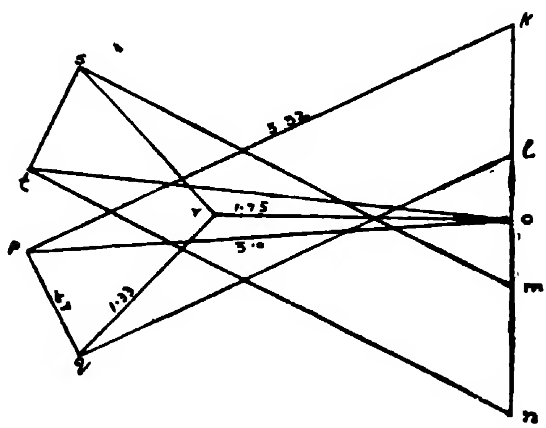
A R. S. beam $3''\times 1\frac{1}{2}''$ @ 4 lbs. with $\frac{I}{y}=1{\cdot}106$, will do for both the purlins and the ridgepole.

Truss.

Span=$21\frac{1}{2}'$. Spacing=8·18′.

Steel truss with $\frac{1}{4}''$ members, $\frac{5}{8}''$ diam. rivets and double $\frac{1}{4}''$ gusset plates. Truss to be cambered: a camber may perhaps be unnecessary, but in a small truss the increase in the stresses is small. Para. 30.





Truss diagram.

Draw the span AB=$21\frac{1}{2}'$: bisect it at C and erect CD, a perpendicular=$\frac{\text{Span}}{4}=5\frac{3}{8}'$. Join AD. BD and bisect each, erecting perpendiculars EG, FH=$\frac{\text{Spa}}{10}=2\frac{1}{8}'$. Join AG, GD, GH, BH, and DH. Then AD, BD are principal rafters: EG, FH struts: AG, BH heel ties: GD, HD upper ties and GH the centre tie.

3. Roof of an Indian Infantry barrack —(contd.). *References.*

Truss diagram —(contd.).

Now draw the external forces, the loads vertically downwards at E, D, F and the reactions vertically upwards at A, B, the centres of the walls.

The system of designating the forces and the truss members usually adopted is "Bow's." Letter all the spaces as shown : then *kl* designates the load at E, *pq* the member EG, etc.

Loads on truss.

There are no loads at A,B ; the weight of the roof between the midpoint of AE and A being carried directly by the wall. The loads *kl*, *lm*, *mn*, are called the panel loads and in the present case are equal to one another. To the roof load must be added to weight of the purlins and of the truss.

Weight of truss$=\cdot08DL^2=\cdot08\times8\cdot18\times21\frac{1}{2}\times21\frac{1}{2}=303$ lbs. of this $\frac{1}{4}$ is carried at each panel point and $\frac{1}{8}$ at each support. Para. 29.

Panel load=roof load+weight of purlin+$\frac{1}{4}$ weight of truss.

$=(32\times8\cdot18\times6)+(8\cdot18\times5)+\frac{303}{4}$

$=1570+41+76=1{,}687$ lbs. $=\cdot753$ tons.

Total load carried $=3\times\cdot753=2\cdot259$ tons.

Half of this, 1·1295 tons, is carried at each support, *no*, *ko*.

Stress Diagram.

Draw the load line vertical marking off on it the panel loads *kl*, *lm*, *mn* : bisect *kn* in *o* : then *no*, *ko* are the reactions. Draw *kp*, *op* parallel to the corresponding members in the truss diagram ; then *pq*, *lq*, followed by *qr*, *or* : this completes one side of the diagram and the other side is drawn in the same way, closing eventually in *r*. It is desirable to use as large a scale as possible both for the truss and stress diagrams.

Stresses.

The stresses are then read off and tabulated. To ascertain whether any particular member is in tension or compression, take a joint in the truss diagram, which includes the member and follow it round clockwise in conjunction with the stress

3. *Roof of an Indian Infantry barrack —(contd.).* *References.*

Stresses—(contd.).

diagram : a line drawn towards the joint in the stress diagram indicates compression and, *vice versâ*, a line drawn away from the joint signifies tension. Thus take the joint D, starting at *l* : *lm* is the load downwards towards the joint; *ms* is towards the joint, indicating compression : *sr* is away from the joint and is therefore a tie.

+indicates compression :—tension.

Stress in principal, *kp*, $=+3{\cdot}32$ tons.
,, ,, strut *pq*, $=+\ {\cdot}67$,,
,, ,, heel tie *op*, $=-3{\cdot}0$,,
,, ,, upper tie. *qr*, $=-1{\cdot}33$,,
,, ,, centre tie, *or*, $=-1{\cdot}75$,,

Principal rafter.
T $3'' \times 2\frac{1}{2}'' \times \frac{5}{16}''$ @ 5·54 lbs.

Length $=6'$. Stress $=+3{\cdot}32$ tons. The lightest T that is strong enough is a $3'' \times 2\frac{1}{2}'' \times \frac{5}{16}''$ @ 5·54 lbs., which will take 4·62 tons over a length of 6′, with ends half fixed. At a pinch a $2\frac{1}{2}'' \times 2\frac{1}{2}'' \times \frac{5}{16}''$ @ 5·01 lbs. would do : it can take 3·23 tons over 6′. If these sections are not available a $2\frac{1}{2}'' \times 2\frac{1}{2}'' \times \frac{3}{8}''$ @ 5·92 lbs. should be used. — Table 10.

Strut.
L $2'' \times 1\frac{1}{2}'' \times \frac{5}{16}''$ @ 2·11 lbs.

Length $2\frac{1}{8}'$: Stress $={\cdot}67$ tons.
For a $\frac{5}{8}''$ rivet, a minimum width of 2″ is necessary, so the smallest possible section, though a good deal too strong, is an angle $2'' \times 1\frac{1}{2}'' \times \frac{5}{16}''$ @ 2·11 lbs. : for a more important truss the thickness would have to be $\frac{1}{4}''$. — Para. 30. Table 11.

Heel tie.
Flat $2\frac{3}{4}'' \times \frac{1}{4}''$ @ 2·34 lbs.

Stress $=3{\cdot}0$ tons. — Para. 14.
$A=\frac{T}{t}=\frac{3.0}{6\frac{1}{4}}={\cdot}48$ or $1{\cdot}92'' \times \frac{1}{4}''$ net.

Adding $\frac{3}{4}''$ for the hole for a $\frac{5}{8}''$ rivet, a steel flat $2\frac{3}{4}'' \times \frac{1}{4}''$ @ 2·34 lbs. will be required. — Table 17.

Upper tie.
Flat $2'' \times \frac{1}{4}''$ @ 1·7 lbs.

Stress $=1{\cdot}33$ tons.
$A=\frac{T}{t}=\frac{1{\cdot}33}{6\frac{1}{4}}={\cdot}213$ or ${\cdot}852 \times \frac{1}{4}''$ net. — Para. 14.
A steel flat $2'' \times \frac{1}{4}''$ @ 1·7 lbs. will do. — Table 17.

Centre tie.
Flat $2'' \times \frac{1}{4}''$ @ 1·7 lbs.

Stress $=1{\cdot}78$ tons.
$A=\frac{T}{t}=\frac{1{\cdot}75}{6\frac{1}{4}}={\cdot}28$ or $1{\cdot}12'' \times \frac{1}{4}''$ net. — Para. 14.
A steel flat $2'' \times \frac{1}{4}''$ @ 1·7 lbs. will do. — Table 17.

Rivets.

As the gusset plates are double, all rivets will be in double shear. To find the number of rivets required

3. *Roof of an Indian Infantry barrack* —(contd.). *References.*

Rivets—(contd.).

at each end of each member, the stress has to be multiplied by the highest factor for either bearing or double shear in table 13. For the principal, which is $\frac{5}{16}''$ thick, the factor is ·64 : for the other members ·8. — Table 13.

Number of rivets at end of—

principal . .	$= 3{\cdot}32 \times {\cdot}64 = 3$
strut . .	$= {\cdot}67 \times {\cdot}8 = 1$
heel tie . .	$= 3{\cdot}0 \times {\cdot}8 = 3$
upper tie . .	$= 1{\cdot}33 \times {\cdot}8 = 2$
centre tie . .	$= 1{\cdot}75 \times {\cdot}8 = 2$

Table of sections.

The sections calculated for members may be tabulated for reference.

Member.	Section.	Number of rivets.
Principal	T $3'' \times 2\frac{1}{2}'' \times \frac{5}{16}''$ @ 5 54 lbs. . .	3
Strut	L $2'' \times \frac{1}{2}'' \times \frac{3}{16}''$ @ 2·11 lbs. . . .	1
Heel tie	Flat $2\frac{3}{4}'' \times \frac{1}{4}''$ @ 2·34 lbs. . . .	3
Upper tie . . .	Flat $2'' \times \frac{1}{4}''$ @ 1·7 lbs.	2
Centre tie . . .	Flat $2'' \times \frac{1}{4}''$ @ 1·7 lbs.	2

Truss for double tiling.

As an example of the use of the constants given in table 14, a truss to carry double tiling will be worked out for the same building.

w, load per sq. ft. = weight of tiles + occasional load.
$= 34 + 15 = 49$ lbs. vertical.

This is a much heavier load than previously taken and it will be better to use heavier purlins, say $4'' \times 1\frac{3}{4}''$ @ 5 lbs., than to space the trusses closer together.

Considering the ridgepole, where the load is not reduced to normal: spacing 6′: — Para. 11.

$$\frac{I}{y_{i}} = \frac{WL}{5} \text{ or } 1{\cdot}834 = \frac{(49 \times 6 \times L) \times L}{5 \times 2240.}$$ — Table 12.

or $L^2 = 70$ and $L = 8{\cdot}36$.

The building being $163\frac{1}{2}'$ long, the nearest suitable spacings are 8·18 and 8·61 : the latter may be chosen.

3. *Roof of an Indian Infantry barrack* —(concld.). *References.*

Truss for double tiling. —(contd.).

Then for a 4 panel truss, cambered: span $21\frac{1}{2}'$ and spacing 8·61′.

W = roof load + weight if purlins + weight of truss carried. — Table 14.

$=(w\ L\ D \times \cdot 84) + (\text{weight of purlins}) + (L^2 \times D \times \cdot 06)$

$=(49 \times 21\frac{1}{2} \times 8{\cdot}61 \times {\cdot}84) + (3 \times 8{\cdot}61 \times 5) + (21\frac{1}{2} \times 21\frac{1}{2} \times 8{\cdot}61 \times {\cdot}06)$

$=7620 + 129 + 239 = 7988$ lbs. $= 3{\cdot}56$ tons.

Member.	Stress tons.	Length feet.	Section	Number of $\frac{5}{8}''$ rivets.	
Principal .	$3{\cdot}56 \times 1{\cdot}47 = 5{\cdot}23$	6′	T $3'' \times 2\frac{1}{2}'' \times \frac{3}{8}''$ @ 6·56 lbs.	$5{\cdot}23 \times {\cdot}53 = 3$	
Strut .	$3{\cdot}56 \times {\cdot}3 = 1{\cdot}07$	$2\frac{1}{8}'$	L $2'' \times 1\frac{1}{2}'' \times \frac{3}{16}''$ @ 2·11 lbs.	$1{\cdot}07 \times {\cdot}8 = 1$	Table 14.
Heel tie .	$3{\cdot}56 \times 1{\cdot}325 = 4{\cdot}72$	Net area. $-6\frac{1}{4}$ $= {\cdot}755$	Equivalent to $3{\cdot}02'' \times {\cdot}25''$, or adding $\frac{3}{4}''$ for the rivet hole, steel flat $3\frac{3}{4}'' \times \frac{1}{4}''$ @ 3·19 lbs	$4{\cdot}72 \times {\cdot}8 = 4$	Table 10. Table 11. Table 17.
Upper tie .	$3{\cdot}56 \times {\cdot}58 = 2{\cdot}06$	$-6\frac{1}{4}$ $= {\cdot}33$	Equivalent to $1{\cdot}32'' \times \frac{1}{4}''$ or a steel flat $2\frac{1}{4}'' \times \frac{1}{4}''$ @ 1·91 lbs	$2{\cdot}06 \times {\cdot}8 = 2$	Table 13.
Centre tie .	$3{\cdot}56 \times {\cdot}78 = 2{\cdot}78$	$-6\frac{1}{4}$ $= {\cdot}442$	Equivalent to $1{\cdot}765'' \times \frac{1}{4}''$ or a steel flat $2\frac{1}{2}'' = \frac{1}{4}''$ @ 2·13 lbs.	$2{\cdot}78 \times {\cdot}8 = 3$	

4. *Roof of a Gunshed.*

Nature of roof.

Single Mangalore tiles on teak battens and 24 G corrugated iron, on steel purlins and trusses. The shed has an internal span of 46′ and is divided into bays, each 9′ wide, end bays being 10′: trusses are supported on pillars between the bays. The pillars in the front wall are 3′ wide, while the back wall is $1\frac{3}{4}'$. Slope of roof 1 in 2. Corrugated iron sheets are lapped 9″ and double rivetted. — Plate XXI.

Load.

Tiles and battens . . 10 lbs. — Table 14

Corrugated iron . . $1\frac{1}{2}$ lbs.

$11\frac{1}{2}$ lbs. vertical or $10\frac{1}{4}$ lbs. normal per sq. ft.

Wind pressure 31 lbs. per sq. ft. normal, for a span of 46′. — Para. 8 (c) and (d).

Total normal load $= 41\frac{1}{4}$ lbs. sq. ft.

4. *Roof of a Gunshed*—(contd.). *References.*

Battens.
Teak: $1'' \times 1\frac{1}{2}''$.

Battens carry no load and may be made the minimum size that is possible with the timber available.

Purlins.
R. S. beams $4'' \times 1\frac{3}{4}''$ 5 lbs.

Purlins must not be further apart than — Para. 21.

The width of the building is 46′ and the length of the roof slope on one side from the ridge to the inner edge of the wall will be $\frac{46}{2}$ sec. θ $\frac{46 \times 1{\cdot}118}{2} = 25{\cdot}7'$. To suit this length purlins must be spaced $\frac{25{\cdot}7}{5} = 5{\cdot}14'$ apart. — Table 4.

End span = 10′ : rest 9′. Beams continuous.

$\frac{I}{y} = \frac{WL}{5} = \frac{(41\frac{1}{2} \times 5{\cdot}14 \times 10) \times 10}{5 \times 2240} = 1{\cdot}89$ or $4'' \times 1\frac{3}{4}''$ @ 5 lbs. is near enough. — Para. 11. Table 12.

Ridgepole.
Double: R. S. beam $3'' \times 1\frac{1}{2}''$ @ 4 lbs.

The ridgepole will be double, and, as the proportion of vertical load is so small, $\frac{I}{y}$ may be taken as half that for purlins = ·86. A $3'' \times 1\frac{1}{2}''$ beam @ 4 lbs. will do. — Para. 16 Table 12.

To prevent any tendency for the roof to slide downwards, the ridgepoles on either side should be connected together by bolts at 2 or 3 intermediate points between trusses.

Truss.

Allowing for a full bearing on the back wall and a similar bearing of the front pillar, the span of the truss will be $46 + (2 \times \frac{1\frac{1}{2}}{2}) = 47\frac{1}{2}'$.

Spacing $9\frac{1}{2}'$.

The front end of the truss over the pillar will be free to move, to permit of expansion and contraction; the end resting on the back wall will be fixed. — Para. 32.

There are 4 purlins on each side, so a 10 panel truss will be required. The length of the centre line of the principal from apex to heel will be $\frac{47\frac{1}{2}}{2}$ sec. $\theta = \frac{47\frac{1}{2} \times 1{\cdot}118}{2} = 26\frac{3}{4}''$. As purlins are spaced 5·14′ apart, the upper panels will each be 5·14′ long and the lowest panel on either side $26{\cdot}75 - (4 \times 5{\cdot}14) = 6{\cdot}19'$. — Table 4.

As appearance is of little importance, no camber need be given: during — Para. 31.

4. *Roof of a Gunshed*—(contd.). *References.*

Truss—(contd.).

construction, however, a camber of 6″ should be arranged for, to allow for deflection.

Though the panels are not quite equal the truss might be worked out by the constants given in table 14 : as, however, several principles are involved, which were not touched on in example 3, the truss is worked out in full detail.

Truss diagram.

The truss diagram is drawn as explained in example 3, the panel points falling under the purlins. The position of the joint connecting the heel and centre tie is obtained by bisecting the principal and drawing a perpendicular to the horizontal line joining the feet of the truss.

Loads.

Vertical load on each panel =roof load+weight of purlins + weight of truss.

The weight of the truss $= \cdot 08\ DL^2$ $= \cdot 08 \times 9\frac{1}{2} \times 47\frac{7}{8} \times 47\frac{7}{8} = 1740$ lbs. Para. 29.

of this $\frac{1}{10}$ or 174 lbs. will be carried at each of the 9 panel points and $\frac{1}{20}$ at each support.

$ab = (\frac{6\cdot 19 + 5\cdot 14}{2} \times 9\frac{1}{2} \times 11\frac{1}{2})$ $+ (1 \times 9\frac{1}{2} \times 5) + 174 = 614 + 48 +$ $174 = 836$ lbs. $= \cdot 378$ tons.

$bc,\ cd,\ de = (5\cdot 14 \times 9\frac{1}{2} \times 11\frac{1}{2})$ $+ (1 \times 9\frac{1}{2}) \times 5 + 174 = 562 + 48 +$ $174 = 784$ lbs. $= \cdot 349$ tons.

$ef = (5\cdot 14 \times 9\frac{1}{2} \times 11\frac{1}{2}) + (2 \times 9\frac{1}{2} \times 5)$ $+ 174 = 562 + 95 + 174$ $= 831$ lbs. $= \cdot 371$ tons.

For wind load :

$ab = \frac{6\cdot 19 + 5\cdot 14}{2} \times 9\frac{1}{2} \times 31$ $= 1668$ lbs. $= \cdot 744$ tons.

$bc,\ cd,\ de = 5\cdot 14 \times 9\frac{1}{2} \times 31$ $= 1514$ lbs. $= \cdot 677$ tons.

$ef = \frac{5\cdot 14}{2} \times 9\frac{1}{2} \times 31$ $= 757$ lbs. $= \cdot 338$ tons.

Stress diagrams.

First draw the diagram for dead load, fig. 2 ; the position of k is found by bisecting the load line. It will be found that the point p cannot be fixed directly : take any point $q/$ on $d\ q$ and complete the triangle $q/r/p/$: draw p/p parallel to $d\ q$ and this will give the position of p.

4. *Roof of a Gunshed*—(contd.). *References*

Stress diagrams —(contd.).

With wind the following conditions may occur:

(*a*) wind blowing on one side of the truss, both ends being fixed due to rusting, etc., of the bearing that is supposed to be capable of moving: fig. 3.

(*b*) wind blowing on left, right end free to move: fig. 4.

(*c*) wind blowing on right, right end free to move: fig. 5.

With symmetrical and symmetrically loaded trusses of this form, the maximum stresses always occur, when the wind is blowing on the fixed side and the diagram for this case only need be drawn. Diagrams for all the cases are given here to illustrate the principles involved. Para. 28.

Case (*a*), fig. 3. Draw the load line *a b c d e f* : take any point X and draw the polar diagram by joining X to the points on the load line. Then in the truss diagram between the load lines at the panel points draw the funicular polygon, A. B being parallel to X*b*, BC, CD, DE to X*c*, X*d*, X*e* respectively: from the points A, E draw AK, BK parallel to X*a*, X*f*, the outer lines of the polar diagram. K gives a point on the line of resultant wind pressure.

To find the reactions, which, when the ends are fixed, will be parallel to the wind pressure, draw LN, MO the reaction lines and parallel lines *fN*, *a*O from the ends of the load line. Join NO and from P, where it cuts the resultant wind pressure line, draw P*k* to the load line parallel to *a*O. Then *ak*, *fk* are the reactions.

The stress diagram again presents difficulty at *p*, but can be completed readily by working backwards along *f t s p* : *t*, *s* are coincident.

Case (*b*), fig. 4. As the right hand end of the truss is free to move, the wall can only supply a vertical reaction, the entire horizontal component being taken up at the fixed end. To find the reactions draw M Q vertical, cutting the lines of resultant wind pressure, K P, in Q. Join Para. 32.

4. *Roof of a Gunshed*—(contd.). *References.*

Stress diagrams —(concld.).

L Q; which gives the direction of the reaction at the fixed end. From the ends of the load line draw *ak*, *fk*, parallel to LQ, MQ : *ak*, *fk* are the reactions.

Case (*c*), fig. 5. L R the direction of resultant at the fixed end is found in the same way as for case (*b*).

Stresses.

It will be seen that the maximum stresses occur when the wind is blowing on the fixed side of the truss, case (*b*) fig. 4, and the other cases need not be considered any further. The stresses can now be measured off and tabulated.

Member.	Dead load stress.	Wind stress	Total stress. tons.
Principal, *al*	+3·6	+4·05	+7·65
Centre strut, *no*	+ ·56	+1·17	+1·73
Side strut, *lm*	+ ·32	+ ·78	+1·1
Heel tie, *kl*	—3·21	—4·99	—8·2
Upper tie, *rs*	—1·45	—3·0	—4·45
Centre tie, *ks*	—1·87	—1·98	— 85
Side tie, *mn*	— ·35	— ·8	—1·

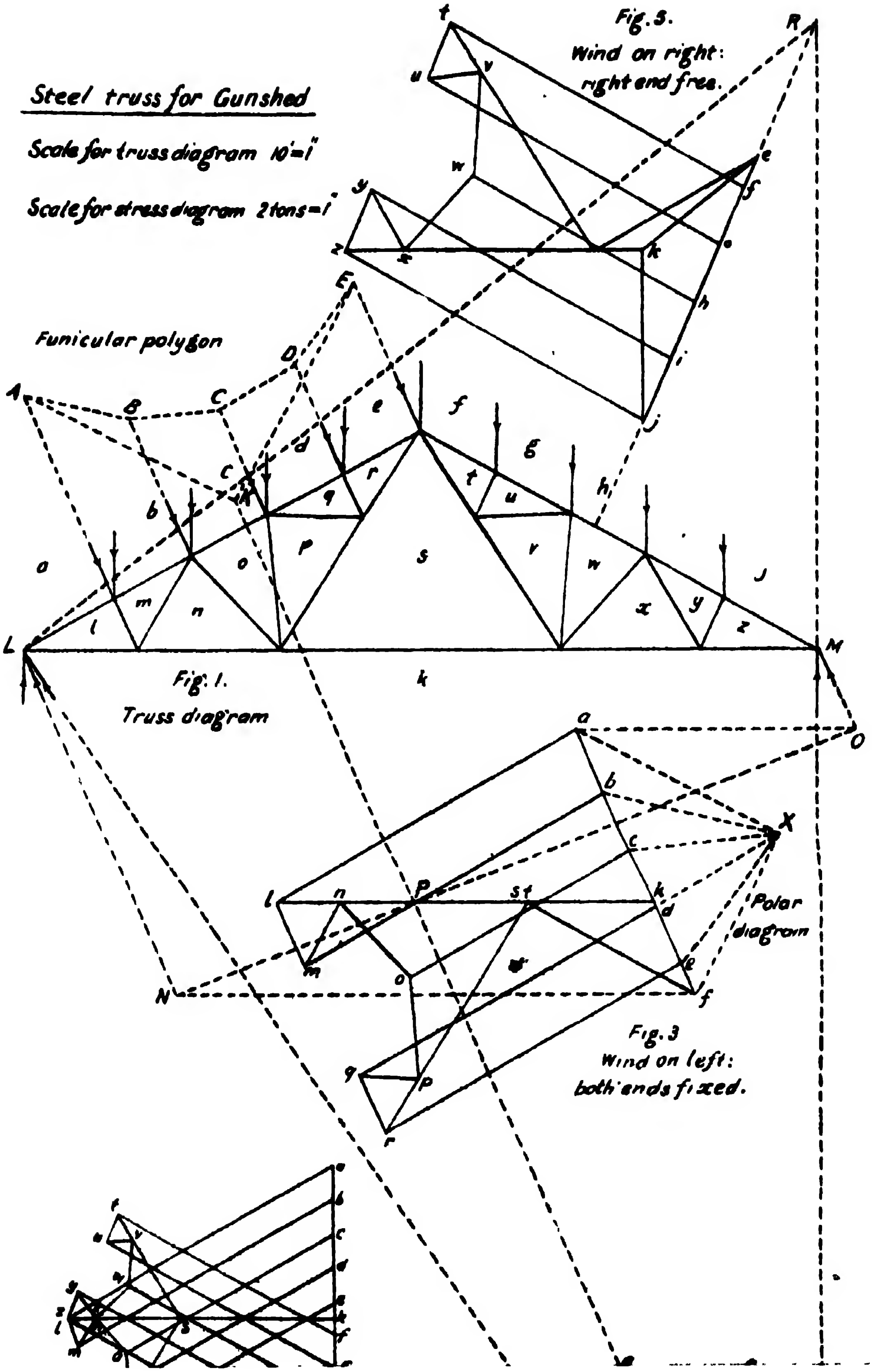
The stress is not a heavy one: the more important members may be double : gusset plates $\frac{3}{8}''$: rivets $\frac{5}{8}''$. Para. 30.

Principal.

Length 5·615′. Stress+7·65 tons, ends half fixed.

⅂⌐ $2'' \times 2\frac{1}{2}'' \times \frac{1}{4}''$ @3·61 lbs.

A pair of $2'' \times 2\frac{1}{2}'' \times \frac{1}{4}''$ angles, each @ 3·61 lbs., will do, long legs being downwards. If not available $2\frac{1}{2}'' \times 2\frac{1}{2}'' \times \frac{1}{4}''$ angles @ 4·04 lbs. each will do. The lightest T that can take the stress is $3'' \times 4'' \times \frac{3}{8}''$ @ 8·48 lbs., so the angles are lighter. Table 11. Para. 30. Table 10.


Steel truss for Gunshed
Scale for truss diagram 10'=1"
Scale for stress diagram 2 tons=1"
Fig. 5.
Wind on right:
right end free.
Funicular polygon
Fig. 1.
Truss diagram
Polar diagram
Fig. 3
Wind on left:
both ends fixed.

	4. *Roof of a Gunshed*—(contd.).	*References.*
Centre strut. ⅂⌐ $2'' \times 2'' \times \frac{1}{4}''$ @ 3·19 lbs.	Length 7·4′. Stress + 1·73 tons. Ends rounded.	
	Table 11 does not go beyond 5′ for struts with ends rounded, but it can be seen that a pair of $2'' \times 2'' \times \frac{1}{4}''$ angles ought to do: $k = \cdot 6$ and $A = 2 \times \cdot 938$.	Table 11.
	$\frac{l}{k} = \frac{7 \cdot 4 \times 12}{\cdot 6} = 148$, corresponding to a stress of 1·3 tons per sq. inch for ends rounded.	Table 7.
	$C = Ac = 1 \cdot 3 \times 2 \times \cdot 938 = 2 \cdot 44$ tons, so the section will do.	Para. 13.
Side strut. L $2'' \times 2'' \times \frac{1}{4}''$ @ 3·19 lbs.	Length 3·2′. Stress + 1·1 tons. Ends rounded. A single, $2'' \times 2'' \times \frac{1}{4}''$ angle can take 2·49 tons over 3′; this makes sufficient allowance for eccentricity, due to the member being on one side of the gusset plate and not central.	
Heel tie. ⅂⌐ $2'' \times 2'' \times \frac{1}{4}''$ @ 3·19 lbs.	Stress = —8·2 tons. $A = \frac{8 \cdot 2}{6\frac{1}{4}} = 1 \cdot 31$ or $5 \cdot 24'' \times \frac{1}{4}''$: with double members, each $2 \cdot 62'' \times \frac{1}{4}''$. Adding $\frac{3}{4}''$ for the rivet hole, $3 \cdot 37'' \times \frac{1}{4}''$, each.	Para. 14.
	The width of an angle equivalent to that of a flat is found by adding the flanges and subtracting the thickness: for a $2'' \times 2'' \times \frac{1}{4}''$ angle, equivalent width $= 2 + 2 - \frac{1}{4} = 3\frac{3}{4}''$. A pair of such angles will do.	Table 11.
Upper tie. Two flats, $2\frac{1}{4}'' \times \frac{1}{4}''$ @ 1·91 lbs.	Stress = —4·45 tons. $A = \frac{4 \cdot 45}{6\frac{1}{4}} = \cdot 712$ or $2 \cdot 85'' \times \frac{1}{4}''$: for double members, each $1 \cdot 42'' \times \frac{1}{4}''$. Adding $\frac{3}{4}''$ for the rivet hole, $2 \cdot 17'' \times \frac{1}{4}''$.	Para. 14.
	Double angles with a minimum width of 2″ would be rather extravagant and the truss is hardly heavy enough to justify their use, nor is any reversal of stress expected.	Para. 30.
	A pair of $2\frac{1}{4}'' \times \frac{1}{4}''$ flats may be used.	Table 17.
Centre tie. Two flats, $2'' \times \frac{1}{4}''$ @ 1·7 lbs.	Stress = —3·85 tons. $A = \frac{3 \cdot 85}{6\frac{1}{4}} = 6 \cdot 16$ or $2 \cdot 46'' \times \frac{1}{4}''$: each $1 \cdot 23'' \times \frac{1}{4}''$. Adding $\frac{3}{4}''$ to the width, a pair of $2'' \times \frac{1}{4}''$ flats will do.	Para. 14. Table 17.
Side tie. Flat $2'' \times \frac{1}{4}''$ @ 1·7 lbs.	Stress = —1·15 tons. $A = \frac{1 \cdot 15}{6\frac{1}{4}} = \cdot 184$ or $\cdot 737'' \times \frac{1}{4}''$. A $2'' \times \frac{1}{4}''$ Flat will do.	Para. 14. Table 17.

4. *Roof of a Gunshed*—(contd.). *References.*

Sag tie.
½″ diam. rod @ ·608 lbs.

As the centre tie is very long and therefore likely to sag by reason of its own weight, a sag tie should be given from the apical gusset plate to the centre of the tie. A 2″ × ¼″ flat or a ½″ diam. rod will do: the ends of the rod must be forged to take a ⅝″ rivet. Table 15.

Distance pieces.

Double members must be connected together at intermediate points by means of a filling piece and a rivet; with struts the spacing of this distance pieces is governed by the length of single strut that will support half the load and in the present instance one distance piece is required in the principals and centre struts. For ties distance pieces are not really required but they render the truss stiffer during erection: one may be given in the heel and upper ties and one each side of the sag tie in the centre tie. Para. 30. Table 11.

Rivets.

In double members the rivets are in double shear and the factor for bearing in a ⅜″ plate should be taken. Single members have the rivets in single shear, but the bearing factor in a ¼″ plate gives a higher result. The number of rivets at each end of each member are: Para. 33. Table 13.

Principal .	$=7{\cdot}65\times{\cdot}53=5$
Centre strut .	$=1{\cdot}73\times{\cdot}53=1$ but give 2.
Side strut .	$=1{\cdot}1\times{\cdot}8=1$
Heel tie . .	$=8{\cdot}2\times{\cdot}53=5$
Upper tie . .	$=4{\cdot}45\times{\cdot}53=3$
Centre tie .	$=3{\cdot}85\times{\cdot}53=3$
Side tie . .	$=1{\cdot}15\times{\cdot}8=1$

Baseplate.

As the truss is not very heavy, a ¼″ baseplate will do. The baseplate may be directly connected to the heel angles: rivets are actually only required to resist the horizontal component, *a* S (fig. 4), of the wind pressure, but in actual practice more are provided and in the present instance 3 each side will do. The width of the plate is made sufficient to take the holding down bolts and the length should be

4. *Roof of a Gunshed*—(contd.). *References.*

Baseplate—(contd.).

about equal to the width: it will be found that the plate is amply large enough to distribute the pressure on the bed-stone. Over the pillar the holes in the baseplate for the holding down bolts should be slotted. Para. 32.

Table of sections.

The sections chosen may now be tabulated :—

Member.	Section.	Number of rivets.
Principal	┐┌ each, 2″ × 2½″ × ¼″ @ 3·61 lbs. .	5
Centre strut	┐┌ each, 2″ × 2″ × ¼″ @ 3·19 lbs. .	2
Side strut	L 2″ × 2″ × ¼″ @ 3·19 lbs. . . .	1
Heel tie	┐┌ each, 2″ × 2″ × ¼″ @ 3·19 lbs. .	5
Upper tie	2 flats, each, 2¼″ × ¼″ @ 1·91 lbs. .	3
Centre tie	2 flats, each 2″ × ¼″ @ 1·7 lbs. . .	3
Side tie	Flat, 2″ × ¼″ @ 1·7 lbs. . .	1
Sag tie	½″ rod @ ·608 lbs.	..

Principal under combined stress.

It might be argued that it would be better to use a truss with fewer panels and to place the purlins along the principal irrespective of where the truss joints came, thereby subjecting the principal to combined transverse and compressive stress. Para. 21.

In the present instance the length of the principal from apex to heel is 26¾′ and to keep the unsupported length of each section under 8′, an eight panel truss would be required, with each panel $\frac{26\frac{3}{4}}{4}=6{\cdot}7'$ long. Para. 21.

4. *Roof of a Gunshed*—(concld.).

References.

Principal under combined stress—(contd.).

Wherever the purlins come, it may be assumed that the load is evenly distributed over each span. It may be shown that in any continuous system of loading, wherever the loads are applied, the maximum bending moment will always be an ordinate of the parabola representing the bending moment for a uniformly distributed load.

The compressive stress will be much the same as for the truss worked out above. C=7·65 tons over 6·7′. Spacing of trusses $9\frac{1}{2}'$.

$\frac{I}{y}=\frac{WL}{5}=\frac{(41\frac{1}{4}\times 9\frac{1}{2}\times 6\cdot7)\times 6\cdot7}{5\times 2240}=1\cdot57.$ Para. II.

Try a pair of $4''\times 3\frac{1}{2}''\times\frac{5}{16}''$ angles @ 7·64 lbs. each, where $A=2\times 2\cdot246=4\cdot492$. $I=2\times 3\cdot46=6\cdot92$. $\frac{I}{y}=2\times 1\cdot22=2\cdot44$. Table 11.

The strut is fixed from moving in the direction of the purlins, so k may be taken for an axis normal to the load $k=\sqrt{\frac{I}{A}}=\sqrt{\frac{6\cdot94}{4\cdot492}}=1\cdot24$, the same as the minimum value for k, so the strut table may be used. Para. 15.

For strength $\frac{I}{y}$ available$=2\cdot44$: $\frac{I}{y}$ required$=1\cdot57$, so that $\frac{1\cdot57\times 100}{2\cdot44}=64\cdot3$ per cent. is employed.

For direct stress strut will take 19·2 tons, while C=7·65 tons, so that $\frac{7\cdot65\times 100}{19\cdot2}=39\cdot8$ per cent. of the available strength is used. Table 11.

Thus $64\cdot3+39\cdot8=104\cdot1$ per cent. of the available strength is used and the strut may be considered strong enough. Para. 15.

It will be seen that the principal now weighs more than double that for the truss worked out above.

5. *Roof of a stable.*

Nature of roof.

Single Allahabad tiles on deodar battens, rafters and purlins on steel cantilever trusses. Bressummers of

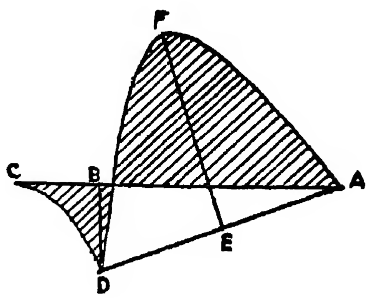
5 —*Roof of a stable*—(contd.)

Nature of roof—(contd.)	deodar. Slope of roof 1 in 2. Stalls are arranged in two rows with a 4′ clear passage between. Each stall is 14′, measured between inner edges of pillars, by $7\frac{1}{2}$′, measured between centres of pillars along the stable. All pillars, $1\frac{1}{2}$′ square.	*References.*
Load.	Tiles and battens 17 lbs. vertical or $15\frac{1}{4}$′ lbs. normal, wind pressure for a span of 38′=27 lbs. sq. ft. Total normal load$=42\frac{1}{4}$ lbs. sq. ft.	Table 1. Para. 8. *c.*
Battens. Deodar: $1'' \times 1\frac{1}{2}''$.	Length of roof from ridge to centre of bressummer$=18\frac{1}{4}'$ sec. $\theta=18\frac{1}{4}\times 1{\cdot}118=20{\cdot}4'$. As there will be two purlins, the average span of the rafter may be taken as $=\frac{20{\cdot}4}{3}=6{\cdot}8'$.	Table 4.
	Spacing of rafters$=\frac{\text{span}}{4}+6''=\frac{6{\cdot}8'}{4}+6''=2{\cdot}2'$.	Para. 20
	Spacing of battens$=1'$. $bd^3=\frac{WL^2}{170}=\frac{(42\frac{1}{4}\times 1\times 2{\cdot}2)\times 2{\cdot}2\times 2{\cdot}2}{170}=2{\cdot}64'$.	Para. 12.
	The nearest larger batten suitable is $1''\times 1\frac{1}{2}''$, with $bd^3=3{\cdot}4$ and this may be spanned to its utmost. $bd^3=\frac{WL^2}{170}$ or $3{\cdot}4=\frac{(42\frac{1}{4}\times 1\times L)\times L^2}{170}$ or $L^3=13{\cdot}67$ and $L=2{\cdot}4'$.	Table 6
	As the load is largely due to wind, a spacing of $2\frac{1}{2}'$ for rafters may safely be adopted and this suits the length of bay, $7\frac{1}{2}'$.	
Rafters. Deodar: $2''\times 4\frac{1}{2}''$.	At the eaves the rafter overhangs beyond the bressummer, with the result that the bending moment in the rafter above the bressummer is reduced when compared with that of a beam if supported on the bressummer and lower purlin and not overhanging. Consequently the upper two spans of the rafter may be made somewhat shorter than the lower span, though the bending moment in each section will remain the same. This point is not ordinarily considered, but with a cantilever truss, every inch of leverage saved means a substantial reduction in the stresses.	

5. Roof of a stable—(contd.). *References.*

Rafters—(contd.).

The length of the roof slope as found above is 20·4′. If a clear horizontal overhang of $1\frac{1}{2}'$ is given beyond the outer edge of the pillar, the length of the cantilevered portion will be $(1\frac{1}{2}+\frac{3}{4})$ sec. $\theta = 2\frac{1}{4}\times 1{\cdot}118 = 2\frac{1}{2}'$ nearly. Table 4.



If A B C is a beam with the portion B C overhanging, the bending moment diagram is represented by the shaded portion, while the diagram for the beam, if only supported at A and B with no overhang would be D F A D. It will be seen that the effect of the overhang is to reduce the maximum bending moment by about half the maximum bending moment for the overhanging portion, B D.

Then if w=load per foot run on the beam, x=the lower span of the rafter, the bending moment for a cantilever being four times that for a supported beam :—

$$1\tfrac{1}{2}\ w\ x^2 - \tfrac{1}{2}\ (6\ w\ 2\tfrac{1}{2}\times 2\tfrac{1}{2}) = 1\tfrac{1}{2}\ w \left(\frac{20{\cdot}4 - x}{2}\right)^2$$

$$x^2 + 13{\cdot}6\,x - 156 = 0.$$

$$x = \sqrt{156 + (6{\cdot}8)^2} - 6{\cdot}8 = 7{\cdot}4.$$

Each upper span $= \frac{20{\cdot}4 - 7{\cdot}4}{2} = 6\frac{1}{2}'$.

(NOTE.—The permissible amount of overhang is limited by the deflection, and should not exceed one-third of the span of the rafter.)

Then span of rafter $=6\frac{1}{2}'$. Spacing $=2\frac{1}{2}'$.

$$bd^2 = \frac{WL^2}{170} = \frac{(42\frac{1}{2}\times 2\frac{1}{2}\times 6\frac{1}{2})\times 6\frac{1}{2}\times 6\frac{1}{2}}{170}$$ Para. 12.

$=172$ or $2''\times 4\frac{1}{2}''$. Table 6.

	5. *Roof of a stable*—(contd.).	*References.*
Purlins and ridgepole. Deodar, $3\frac{1}{2}'' \times 6\frac{1}{2}''$.	Span $7\frac{1}{2}'$. Width of roof carried $=\frac{7\cdot4+6\cdot5}{2}=6\cdot95'$. Continuous.	
	$bd^2=\frac{WL}{115}=\frac{(42\frac{3}{4}\times6\cdot95\times7\frac{1}{2})\times7\frac{1}{2}}{115}=143\cdot5$ or $3\frac{1}{2}''=6\frac{1}{2}''$.	Para. 11. Table 5.
	The width of roof, carried by the ridgepole is rather less, also a large proportion of the load normal: the same section will do.	
Bressummer. Deodar, $4\frac{1}{4}'' \times 5\frac{1}{2}''$.	Span $7\frac{1}{2}'$. Width of roof carried $=\frac{7\cdot4}{2}+2\frac{1}{2}=6\cdot2'$. Continuous.	Para. 11.
	$bd^2=\frac{WL}{115}=\frac{(42\frac{3}{4}\times6\cdot2\times7\frac{1}{2})\times7\frac{1}{2}}{115}=128$ or $4\frac{1}{4}''\times5\frac{1}{2}''$.	Table 5.
Truss diagram.	First draw a line representing the lower edge of the rafter, marking on it the centre lines of the ridgepole, purlins and bressummer; 6″ lower, the depth of the purlins, draw in the truss.	
Loads on truss.	Vertical load = weight of tiling + weight of truss. Weight of truss $=\cdot08DL^2=\cdot08\times7\frac{1}{2}\times22\frac{3}{4}\times22\frac{3}{4}$ $=310$ lbs. of which $\frac{1}{5}$th $=62$ lbs. may be taken as coming on each panel point.	Para. 29.
	$ab=(\frac{7\cdot4+6\cdot5}{2}\times7\frac{1}{2}\times17)+62$ $=886+62=948$ lbs. $=\cdot423$ tons.	
	bc, $cd=(6\cdot5\times7\frac{1}{2}\times17)+62=829+62=891$ lbs. $=\cdot398$ tons.	
	Wind load:	
	$ab=\frac{7\cdot4+6\cdot5}{2}\times7\frac{1}{2}\times27=1408$ lbs. $=\cdot628$ tons.	
	$bc=6\cdot5\times7\frac{1}{2}\times27=1317$ lbs. $=\cdot588$ tons.	
	$cd=\frac{1}{2}\,bc=\cdot294$ tons.	
Stress diagram.	It is considered that the worst condition likely to occur will be when the wind is blowing downwards on one side and the upward force of the wind on the opposite side is just sufficient to neutralize the weight of the tiles. If the upward force increases the tiles will blow away, instantly relieving the pressure.	
	Three diagrams will be required.	

5. *Roof of a stable*—(contd.) *References.*

Stress diagram—(contd.).

(*a*) dead load, both sides loaded.

(*b*) dead load, one side only loaded.

(*c*) wind load.

Case (*a*), fig. 2 presents no difficulty and need only be drawn for half the truss.

Case (*b*), fig. 3. There will only be a half load, ·199 tons, at the apex. The position of the resultant may be found by the method explained in example 4 or by taking moments about the heel of the truss: if x= the distance of the resultant from the heel.

x (·423+·398+·199)=(·398×6·5) +(·199×12·7).

x=5·02′.

The magnitudes of the reactions are found as described in example 4.

Case (*c*), fig. 4. The same procedure is followed as for case (*b*).

Stresses.

Member.	Dead load both sides.	Dead load one side.	Wind.	Maximum total stress tons.
Upper boom, *ck*	—1·25	—1·25	—1·44	—2·69
Lower boom, outer part, *ah*.	+ ·85	+ ·85	+1·38	+2·23
Lower boom, central part, *lg*.	+ ·76	+ ·36	— ·04	+ ·76 — ·04
Side strut, *hk*	+ ·37	+ ·37	+ ·62	+ ·99
Apical strut, *lm*, *kl*	+ ·84	+1·71 — ·86	+1·85 — ·86	+3·56 —1·72

The truss is not a large one, but some of the struts are long and rather heavy sections will be required. The more important members may be double: rivets ⅝″: gusset plates single ⅜″. Para. 31.

Upper boom.

L 2½″×2″×¼″ @ 3·61 lbs.

Stress—2·69 tons.

$A=\frac{T}{f}=\frac{2\cdot69}{6\frac{1}{4}}=\cdot431$ or 1·72″×¼″. Para. 14.

Allowing for ⅝″ hole, 2½″×¼″ is required. In order to support the Table 11.

Steel cantilever truss for stable

Truss diagram—scale 6' = 1"

Stress diagram—scale ·6 tons = 1"

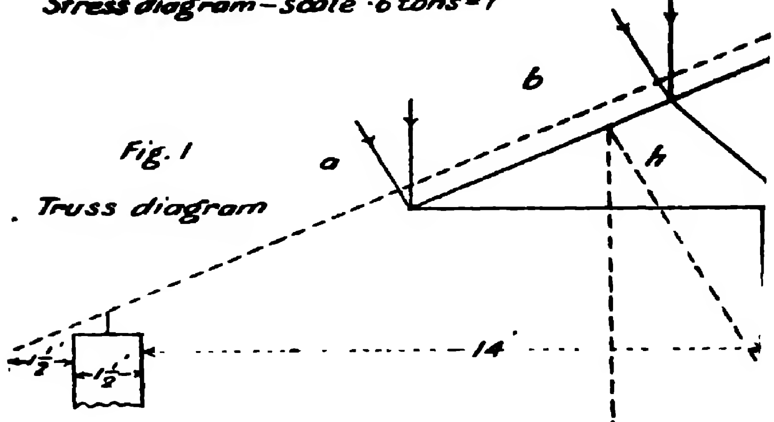


Fig. 1

Truss diagram

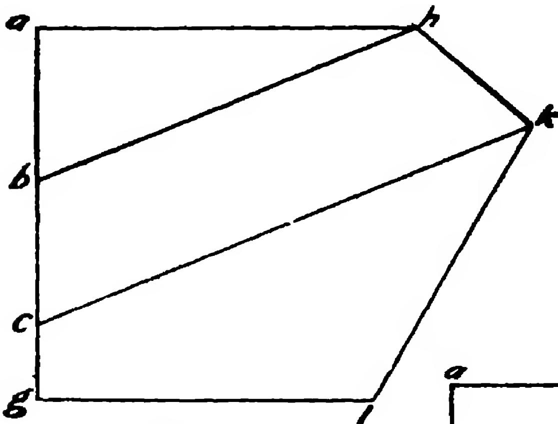
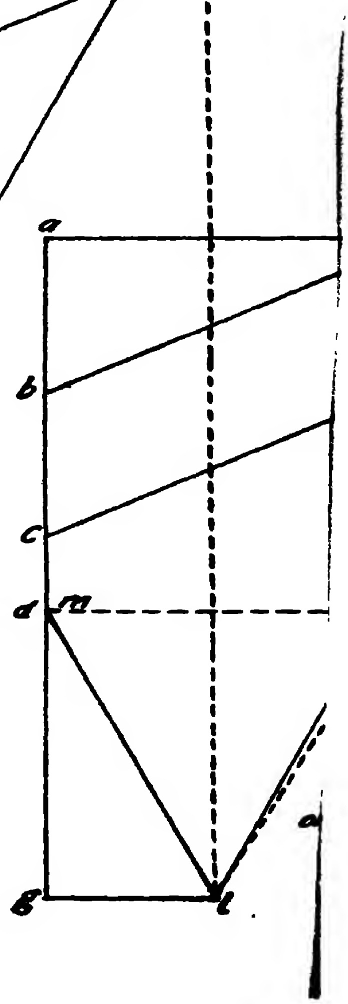


Fig. 2

Dead load

Both sides loaded



	5. *Roof of a stable*—(contd.).	***References.***
Upper boom—(contd.).	purlins an angle section will be convenient, say $2\frac{1}{2}'' \times 2'' \times \frac{1}{4}''$ with an equivalent area of $4\frac{1}{4}'' \times \frac{1}{4}''$: this allows plenty of margin for the eccentricity due to using a single member with a single gusset plate.	
Lower boom. ┐┌ $2\frac{1}{2}'' \times 2'' \times \frac{1}{4}''$ @ $2 \times 3{\cdot}61$ lbs.	Outer part, stress $+2{\cdot}23$ tons; length $8{\cdot}7'$. Central part, stress $+{\cdot}76$ tons: length $5\frac{1}{2}'$.	
	If the same section is used throughout ends may be taken as half fixed. If $\frac{l}{k}$ is kept under 150, k must be not less than $\frac{8{\cdot}7 \times 12}{150} = {\cdot}695$. The lightest section satisfying this value of k is a pair of $2\frac{1}{2}'' \times 2'' \times \frac{1}{4}''$ angles, long legs together: the section can take $5{\cdot}38$ tons over $8'$.	Para. 13. Table 11.
	For the centre portion a single $2'' \times 2'' \times \frac{1}{4}''$ angle would do, but it will be better to carry the larger section right through, as the horizontal wind stress will be distributed better between the two pillars.	Table 11.
Side strut. L $2\frac{1}{2}'' \times 2'' \times \frac{1}{4}''$ @ $3{\cdot}61$ lbs.	Stress $+{\cdot}99$ tons. Length $4'$. Ends rounded. A $2'' \times 2'' \times \frac{1}{4}''$ angle would do, but to allow for eccentricity with a single member use, $2\frac{1}{2}'' \times 2'' \times \frac{1}{4}''$.	Table 11.
Apical strut. ┐┌ $2\frac{1}{2}'' \times 2'' \times \frac{1}{4}''$ @ $2 \times 3{\cdot}61$ lbs.	Stress $+3{\cdot}56$ tons or $-1{\cdot}72$ tons. Ends rounded. Length $6{\cdot}3'$. From an inspection of table 11, it will be seen that a pair of $2\frac{1}{2}'' \times 2'' \times \frac{1}{4}''$ angles, as used for the lower boom should do: $k = {\cdot}77$. $A = 1{\cdot}063$.	Table 11.
	$\frac{l}{k} = \frac{6{\cdot}3 \times 12}{{\cdot}77} = 98$, corresponding to $2{\cdot}4$ tons per square inch.	Table 7. Para. 13.
	$C = Ac = 1{\cdot}063 \times 2 \times 2{\cdot}4 = 5{\cdot}1$ tons.	
Rivets.	Number of rivets at each end of each member.	Table 13.

Upper boom	$= 2{\cdot}69 \times {\cdot}8 = 3$
Lower boom	$= 2{\cdot}23 \times {\cdot}8 = 2$
Side strut	$= {\cdot}99 \times {\cdot}8 = 1$
Apical strut	$= 3{\cdot}56 \times {\cdot}8 = 3$

5. *Roof of a stable*—(contd.). *References.*

Stability of pillars. The reactions measured from the diagrams are :—

Pillar.	Vertical.			Horizontal Wind fig. 4.
	Dead load one side fig. 3.	Wind fig. 4.	Total.	
Windward	*ag* : 1·8 down	*eg* : 2·1 down	3·9 down	*ao* : 1·07
Leeward	*gd* : ·78 up	*pd* : ·77 up	1·55 up	*pg* : ·39

The downward and horizontal pressures are easily resisted, but the upward reaction of 1·55 tons=3470 lbs. requires consideration. The holding down bolts would have to be $\frac{3470}{1\frac{1}{4}\times1\frac{1}{4}\times120}=12{\cdot}85'$ long, if there was nothing but the masonry to resist the force. — Table 1.

Before, however, the truss can overturn, the rafters must be broken at the end of the truss on either side: also the adhesion of the mortar in the pillars offers some resistance.

To find the force P at the end of the truss, take moments about the opposite end :—

$(P \times 22{\cdot}8)+(1{\cdot}55\times8{\cdot}6)=(3{\cdot}9\times 14{\cdot}1)$.

P =1·83 tons =4,100 lbs. vertical or 3,660 lbs. normal.

The rafter has a span of 20·4′, and a section $2''\times4\frac{1}{2}''$: $ba^2=\frac{WL}{115}$ or $W=\frac{115\times50{\cdot}6}{20{\cdot}4}=285$ lbs. distributed, or $142\frac{1}{2}$ lbs. concentrated at the centre, with a factor of safety of 8. If the rafters are jointed alternately at the upper and lower purlins, bound with hoop iron perhaps, and securely spiked to the purlins, they should each be capable of resisting a load of 150 lbs. without breaking. There are three rafters each side and together they can resist $6\times150=900$ lbs. or $\frac{900\times100}{3660}=$say 25% of the total force. — Para 11. Table 5. Table 3.

5. *Roof of a stable*—(concld.). *References.*

Stability of pillars (contd.).

Taking the adhesive strength of the lime mortar at $2\frac{1}{2}$ lbs. per square inch, the pillar can resist, in this respect $18 \times 18 \times 2\frac{1}{2} = 810$ lbs. or $\frac{810}{3470} = 23$ per cent. of the total force.

The top of the windward pillar can also afford a good deal of resistance and, taking all these factors into consideration, 5′ long holding down bolts should be strong enough.

Table of sections.

The sections chosen may now be tabulated :—

Member.	Section.	Number of rivets.
Upper boom	L $2\frac{1}{2}'' \times 2'' \times \frac{1}{4}''$ @ 3·61 lbs.	3
Lower boom	┐┌ Do. each do.	2
Side strut	L Do. do.	1
Apical strut	┐┌ Do each do.	3

If there is any difficulty about obtaining the above section, a $2\frac{1}{4}'' \times 2\frac{1}{4}'' \times \frac{1}{4}''$ L, which weighs the same, may be used.

6. *Trussed beams.*

A. WOODEN BEAM WITH SINGLE STRUT.

Trussed beam of deodar with a single strut, spaced 5′ apart and carrying a roof of 6″ mud on flat tiles on deodar battens. Width of building 14′.

Load.

Clay, $\frac{6}{12} \times 130 = 65$ ⎫
Tiles and battens $= 10$ ⎬ 105 lbs. sq. foot.
Occasional load $= 30$ ⎭

Table 1.
Para. 8 (*b*).

Battens.
deodar : $2'' \times 3\frac{3}{4}''$.

Span 5′. Spacing 1′. Deflection not to exceed $\frac{L}{40}$. Minimum width 2.″.

Para. 5.

$bd^2 = \frac{WL}{115} = \frac{(105 \times 1 \times 5) \times 5}{115}$
$= 22{\cdot}8$

$bd^3 = \frac{WL^2}{170} \times \frac{4}{3} = \frac{(105 \times 1 \times 5) \times 5 \times 5 \times 4}{170 \times 3} = 103$ } or $2'' \times 3\frac{3}{4}''$

Paras. 11, 12
Tables 5, 6.

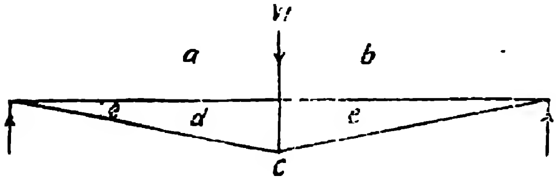
Stresses in members.

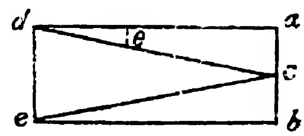
Span, allowing for 6″ bearing on walls, $= 15'$. Spacing 5′. Length of strut $= \frac{\text{span}}{10} = \frac{15 \times 12}{10} = 18''$.

6. *Trussed beams*—(contd.) ***References.***

Stresses in members—(contd.).

Draw the diagram and stress diagram.





$W = ab = 105 \times \frac{15}{2} \times 5 = 3{,}940$ lbs.

Stress in beam $= ad = ac \cot \theta = \frac{3940}{2} \times \frac{7\frac{1}{2}}{1\frac{1}{2}} = 9{,}850$ lbs. compression.

Stress in strut $= de = W = 3{,}940$ lbs.

in tie $= cd = ac \operatorname{cosec} \theta = \frac{3940}{2} \times \frac{\sqrt{7\frac{1}{2}^2 \times 1\frac{1}{2}^2}}{1\frac{1}{2}} = 10{,}030$ lbs.

Beam deodar: $5'' \times 9''$ (5 apart).

The beam is under combined stress, but as it is fixed by the battens from moving in the direction of its width, its depth may be taken as the least dimension. Ends half fixed, as the beam is continuous. — Para. 15; Para. 13

$W = 3{,}940$ lbs. as calculated above. — Para. 11.

For transverse stress:

$bd^2 = \frac{WL}{115} = \frac{3940 \times 7\frac{1}{2}}{115} = 255$ or $3{\cdot}13'' \times 9''$. — Table 5.

With a depth of $9''$: $\frac{l}{d} = \frac{7\frac{1}{2} \times 12}{9} = 10$, corresponding to a stress of 630 lbs. per square inch. — Para. 13.

$A = \frac{C}{c} = \frac{9850}{630} = 15{\cdot}62$ square inch or $1{\cdot}74'' \times 9''$. — Table 8.

Adding the widths, $5'' \times 9''$ will do. — Para. 15.

Strut. deodar: $2\frac{1}{2}'' \times 2\frac{1}{2}''$

Stress, 3,940 lbs. Length $1\frac{1}{2}'$.

Assume $b = 2\frac{1}{2}''$, $\frac{l}{b} = \frac{1\frac{1}{2} \times 12}{2\frac{1}{2}} = 7{\cdot}2$. — Para. 13.

The strut is a short one and $c =$ 700 lbs. square inch. — Table 1.

$A = \frac{C}{c} = \frac{3940}{700} = 5{\cdot}63$ or say $2\frac{1}{2}'' \times 2\frac{1}{2}''$.

Tie. $1''$ diameter rod: ends upset.

Stress $= 10{,}030$ lbs. $= 4{\cdot}3$ tons. — Table 15.

With ends upset a $1''$ rod will do: if the ends are not upset a $1\frac{1}{8}''$ rod is required.

B. STEEL BEAM WITH TWO STRUTS.

Trussed beam of steel with two struts, loaded as before. Width of room 20′. Steel battens to be used.

6. *Trussed beams*—(contd.). *References.*

Battens
T $2'' \times 2'' \times \frac{1}{4}''$ @ 3·32 lbs. (1′ apart).

Span 5′. Spacing 1′. If 15′ lengths are used, treat as continuous.

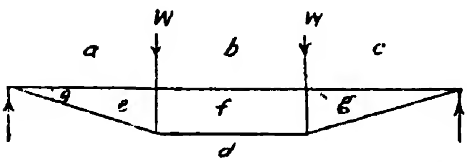
$\frac{I}{y} = \frac{WL}{5} = \frac{(105 \times 1 \times 5) \times 5}{5 \times 2240}$ ·234 or T $2'' \times 2'' \times \frac{1}{4}''$. — Para. 11. Table 12.

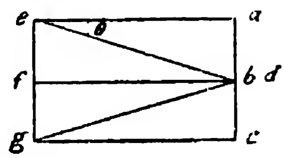
Stresses

Span allowing for 6″ bearing on each wall = 21′. Struts to be $\frac{\text{span}}{10} =$ = 2·1′. Spacing 5′.

Allowance must be made for the weight of the battens = 3·32 × 5 = 16 lbs. per sq. foot: assuming that wooden battens were taken as weighing 2 lbs. square feet, load = 105—2+16 = 119 lbs. square feet.

Proceeding as before:





$W = ab$ or $bc = \frac{21}{3} \times 5 \times 119 = 4{,}170$ lbs. $= 1{\cdot}86$ tons.

Compression in beam $= ae = ab \cot\theta$ $= 1{\cdot}86 \times \frac{7}{2{\cdot}1} = 6{\cdot}2$ tons.

Compression in strut $= ef = W = 1{\cdot}86$ tons.

Tension in outer tie $= de = ab \operatorname{cosec}\theta$ $= 1{\cdot}86 \times \frac{\sqrt{7^2 + 2{\cdot}1^2}}{2{\cdot}1} = 6{\cdot}48$ tons.

Tension in centre tie $= df = ae = 6{\cdot}2$ tons.

The central rectangle must be cross braced if a rolling load is anticipated, as on a bridge.

Beam.
R S. $5'' \times 3''$ @ 11 lbs. (5 apart).

Span 7′. $W = 1{\cdot}86$ tons. $C = 6{\cdot}2$ tons Ends half fixed, and the radius of gyration may be taken about the shorter axis. — Paras. 13, 15.

Try $5'' \times 3''$ @ 11 lbs.: $A = 3{\cdot}235$ $I = 13{\cdot}61$. $\frac{I}{y} = 5{\cdot}444$. k max $= \sqrt{\frac{I}{A}} = \sqrt{\frac{13{\cdot}61}{3{\cdot}235}} = 2{\cdot}05$. — Table 12.

For tranverse strength.
$\frac{I}{y} = \frac{WL}{5} = \frac{1{\cdot}86 \times 7}{5} = 2{\cdot}61$, or $\frac{2{\cdot}61 \times 100}{5{\cdot}44}$ = 48 per cent. of the available strength is utilized. — Para. 11.

6. *Trussed beams*—(concld.) *References.*

Beam—(contd.).

For direct stress.
$\frac{l}{k} = \frac{7 \times 12}{2{\cdot}05} = 41$ corresponding to a stress of 4·89 tons per square inch. Para. 13. Table 7.
$C = Ac = 3{\cdot}235 \times 4{\cdot}89 = 16{\cdot}1$. Thus $\frac{6{\cdot}2 \times 100}{6{\cdot}1} = 38\frac{1}{2}$ per cent. of the available strength is required.
Therefore as only $48 + 38\frac{1}{2} = 86\frac{1}{2}$ per cent. of the available strength is required the beam is strong enough. Para. 15.

Strut.
L $2'' \times 1\frac{1}{2}'' \times \frac{3}{16}''$ @ 2·11 lbs.

Stress 1·86 tons. Length 2·1′. Ends rounded. An angle $2'' \times 1\frac{1}{2}'' \times \frac{3}{16}''$ will do. Table 11

Tie.
$1\frac{1}{4}''$ rod : ends upset.

The stress varies but little and the same section may be used throughout. Maximum stress = 6·48 tons. A $1\frac{1}{4}''$ rod with upset ends or $1\frac{3}{8}''$ with ends directly screwed will do. Table 15.

7. *Boarded floor.*

Nature of floor.

Room $16' \times 14'$ in the upper story of a subordinate's quarter. Floor to consist of $1\frac{1}{2}''$ teak boards on teak joists on rolled steel beams. Joists to be not more than 18″ apart.
(NOTE.—The boards would actually be strong enough to span a good deal more, but, to ensure stiffness and to provide for wear and tear, the spacing of the joists should not exceed 18″.)

Loads.

Boarding $\frac{1\frac{1}{2}}{12} \times 52 = 6\frac{1}{2}$ } $96\frac{1}{2}$ lbs. per Table 1.
Temporary load = 90 } sq. foot. Para. 10.

Joists.
Teak, $1\frac{3}{4}'' \times 3\frac{1}{2}''$
($1\frac{1}{2}'$ apart).

For spacing of main beams, taking the span as 15′, allowing for bearings: Para. 34.
$$D = \frac{L + D_1}{4} = \frac{15 + 1\frac{1}{2}}{4} = 4\frac{1}{8}'.$$

The next higher spacing to suit a length of 17′ allowing for bearings is $4\frac{1}{4}'$.
Span of joists $= 4\frac{1}{4}'$. Spacing $1\frac{1}{2}'$. Deflection not to exceed $\frac{L}{40}$. Minimum width to take screws $= 1\frac{3}{4}''$. Para. 5.
$bd^2 = \frac{WL}{165} = \frac{(96\frac{1}{2} \times 1\frac{1}{2} \times 4\frac{1}{4}) \times 4\frac{1}{4}}{165} = 15{\cdot}85$ or $1\frac{3}{4}'' \times 3''$. Para. 11. Table 5.
$bd^3 = \frac{WL^2}{215} \times = \frac{(96\frac{1}{2} \times 1\frac{1}{2} \times 4\frac{1}{4}) \times 4\frac{1}{4} \times 4\frac{1}{4} \times 4}{215 \times 3}$ $= 69$ o $1\frac{3}{4}'' \times 3\frac{1}{2}''$. Para. 12 Table.6
If the josts rest on the main beams, they may be treated a continuous and the smaller section taken.

7. *Boarded floor*—(concld.) *References.*

Main beams.
R. S. 7″ × 4″ @ 16 lbs. (4¼′ apart).

Span 15′. Spacing 4¼′. Deflection $\frac{L}{40}$ Para. 5.

$\frac{I}{y}=\frac{WL}{5}=\frac{(96\frac{1}{4}\times 4\frac{1}{4}\times 15)\times 15}{5\times 2240}=$ 8·24 Para. 11.
or 7″ × 4″ @ 16 lbs. Table 12.
$I=\frac{WL^2}{17\cdot 8}\frac{4}{3}\times=\frac{(96\frac{1}{4}\times 4\frac{1}{4}\times 15)\times 15\times 15\times 4}{17\cdot 8\times 2240\times 3}$ Para. 12.
$=46\cdot 3$ or 8″ × 4″ @ 18 lbs.

I for a 7″ × 4″ beam = 39·21· The load is not very heavy and the semi-fixing of the beams in the walls will reduce the deflection sufficiently to justify the use of the lighter beam. Para. 36.

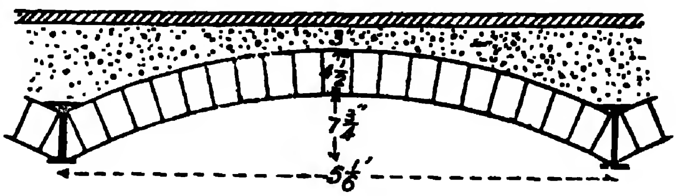
8. *Jack arch floor.*

Nature of floor.

Room 44′ × 30′ in the upper floor of an Institute. Floor to consist of 1½″ stone flagging on a minimum thickness of 3″ of lime concrete, on 4½″ brick arches, on steel joists and steel main beams.

Arrangment of floor.

The arrangement of the floor is shown in the sketch. A 5⅙′ span for the



jack arches will suit the width of 31′. allowing an extra 6″ either side for the end spans. Rise $=\frac{\text{span}}{8}=\frac{5\frac{1}{6}}{8}$ $=7\frac{3}{4}$″. The average thickness of the concrete may be taken as 6″. Para. 37.

For spacing of main beams, span being 31′.

$D=\frac{L+D}{4}=\frac{31+5\frac{1}{6}}{4}=9\cdot 03'$. Para. 34.

Allowing 6″ either end for bearings, a spacing of 9′ will suit the length of 45′.

Load.

Flagging $=\frac{1}{8}\times 156=19\frac{1}{2}$	234 lbs. = ·1045 tons per square foot.	Table 1.
Concrete $=\frac{1}{2}\times 115=57\frac{1}{2}$		Para. 10.
Brick arches $=\frac{3}{8}\times 120=45$		
Temporary load -- 112		

8. *Jack arch floor*—(contd.). — ***References.***

Joists.

R. S. 7″ × 4″ @ 16 lbs. (5¼″ apart).

Span 9′. Spacing 5¼′. Deflection $\frac{L}{40}$ — Para. 5.

$$\left.\begin{aligned} \frac{I}{y} &= \frac{WL}{5} = \frac{(\cdot1045\times5\frac{1}{4}\times9)\times9}{5} \\ &= 8\cdot69 \\ I &= \frac{WL^2}{17\cdot88}\times\frac{4}{3} = \\ &\frac{(\cdot1045\times5\frac{1}{4}\times9)\times9\times9\times4}{17\cdot8\times3} = 29\cdot2 \end{aligned}\right\} \text{7″} \times \text{4″ @ 16 lbs.}$$

Paras. 11, 12. Table 12.

Main beams.

R. S. 24″ × 7″ @ 100 lbs. (9′ apart).

Span 31′. Spacing 9′. Deflection $\frac{L}{40}$ — Para. 5.

$$\left.\begin{aligned} \frac{I}{y} &= \frac{WL}{5} = \frac{(\cdot1045\times9\times31)\times31}{5} \\ &= 181 \\ I &= \frac{WL^2}{17\cdot8}\times\frac{4}{3} = \\ &\frac{(\cdot1045\times9\times31)\times31\times31\times4}{17\cdot8\times3} \\ &= 2100 \end{aligned}\right\} \text{24″} \times \text{7″ @ 100 lbs.}$$

Paras. 11, 12. Table 12.

Sufficient margin is allowed in each case for the weight of the beam. — Para. 7.

Tie rods.

⅞″ diam : (5¼′ apart).

For end spans. — Para. 37.

$$T = \frac{1\cdot5\,wL^2}{R} = \frac{1\cdot5\times1045\times5\times5}{7\frac{1}{2}} = \cdot507$$

tons per foot run.

Spacing of rods not to exceed 20 × width of supporting beams = 20 × 4″ = 6·67′.

A ⅞″ rod, not upset, will resist a tensile stress of 2·64 tons and so may be spaced at $\frac{2\cdot64}{\cdot507} = 5\cdot21$ or say 5¼′ intervals.

(Note.—With such a heavy floor, the pressure on the walls under the beams and on the foundations should be investigated.)

9. *Reinforced concrete floor.*

Nature of floor.

Upper floor for a factory: area to be floored 90′ × 48′. To consist of a reinforced concrete slab on beams and columns of the same material built monolithically. The floor will carry light machinery and a superincumbent load of 150 lbs. a square foot must be allowed for. Height of columns supporting the floor = 16′. Soil can safely withstand a pressure of 1½ tons a square foot. — Para. 10.

Arrangement of beams and pillars.

The wear and tear on the floor will not be very great, but, as the load is moderately heavy, a 4″ slab may be given. To develop the full strength of the slab, so as to use as few ribs as possible, it should be continuous on all four sides, the span in both directions being the same. — Para. 45.

9. *Reinforced concrete floor*—(contd.). **References.**

Arrangement of beams and pillars—(contd.).

Superincumbent $=150$ } 200 lbs. per sq.
Slab $\frac{4}{12}\times 150=50$ } foot on slab. — Table 1

Effective depth $=3''$. Consider a $12''$ strip in a slab continuous on all four sides, with $L^1=L^2$: — Para. 44. Para. 45.

$bd^2=\frac{WL}{m}\times\frac{2}{3}\times\cdot 5=\frac{WL^2}{m}\times\frac{1}{3}$ or $L^2=\frac{m\times 12\times 3\times 3\times 3}{200}=1\cdot 62m$. — Para. 40.

With $p=\frac{1}{2}$, $m=48$, $L^2=1\cdot 62\times 48=77\cdot 8$ and $L=8\cdot 82'$.

$p=\frac{3}{4}$, $m=67$, $L^2=1\cdot 62\times 67=108\cdot 6$ and $L=10\cdot 43'$.

$p=1$, $m=72$, $L^2=1\cdot 62\times 72=116\cdot 6$ and $L=10\cdot 8'$.

A spacing of $8\cdot 82'$ is rather too close for columns and it will be better to adopt $10\frac{1}{2}$.'

Lengthways, intermediate spans $10\frac{1}{2}'$ end spans $=\frac{49-(3\times 10\frac{1}{2})}{2}=8\frac{3}{4}'$.

Crossways, intermediate spans $10\frac{1}{2}$,' end spans $=\frac{91-(7\times 10\frac{1}{2})}{2}=8\frac{3}{4}'$. In each case a foot is added to the dimensions of the area to allow for bearings. The reduction in the end spans will make sufficient allowance for non-continuity at the walls. — Para. 41.

A single row of columns may be given down the centre: if there was no objection to more numerous columns, the best arrangement would be for columns $10\frac{1}{2}'$ apart in either direction.

Slab.

A $4''$ slab, $3''$ effective depth, with $\frac{3}{4}$ per cent. reinforcement in both directions, will be used.

$A_t=\frac{p\,b\,d}{100}\quad\frac{\times 12\times 3}{100}=\cdot 27$ square inches per foot.

$\frac{3}{8}''$ rods, area $\cdot 1104$, $\frac{\cdot 1104\times 12}{27}=4\cdot 9$, say $5''$ apart in both directions will do. — Table 15. Para. 45.

Over the supports, where there will be a negative bending moment equal to that at the centre of the span, the same area of metal must be given along the upper edge: this may be arranged for by turning up all the rods at a distance of $\frac{L}{4}=\frac{10\frac{1}{2}}{4}=2\cdot 6125'$ from the support or by turning-up half the rods only and providing additional rods over the support, extending on either side to the

9. *Reinforced concrete floor*—(contd.). *References.*

Slab—(contd.).

turning up point. The latter arrangement is preferable and is more suited to heavy concentrated loads placed anywhere on the span.

Secondary beams.

Span $10\frac{1}{2}'$. Spacing $10\frac{1}{2}'$.

Superincumbent $= 10\frac{1}{2} \times 150 = 1575$
Slab $= 10\frac{1}{2} \times \frac{4}{12} \times 150 = 525$
Rib = say 100
} 2,200 lbs. foot run. — Table 1.

$b_s = \frac{1}{3} \times \text{span} = \frac{1}{3} \times 12 \times 10\frac{1}{2} = 42$
$15 \times d_s = 15 \times 4 = 60$
$\frac{3}{4} \times \text{spacing} = \frac{3}{4} \times 12 \times 10\frac{1}{2} = 94\frac{1}{2}$
} take 42″. — Para. 49.

Assume $p = \frac{1}{2}$: beam continuous. — Para. 51.

$b_s\, d^2 = \frac{WL}{48} \times \frac{2}{3} = \frac{(2200 \times 10\frac{1}{2}) \times 10\frac{1}{2} \times 2}{48 \times 3} = 3370$ — Para. 40.
or 42″ × 9″.

$d = \frac{9}{10\frac{1}{2} \times 12} = \frac{1}{14} \times \text{span}$ and will do. — para. 49.

$\frac{d}{d_s} = \frac{9}{4} = 2\frac{1}{4}$ and so the neutral axis falls in the slab. — Para. 51.

$A_t = \frac{p\,b\,d}{100} = \frac{\frac{1}{2} \times 42 \times 9}{100} = 1{\cdot}89$ square inches.

Say 8 rods, $\frac{9}{16}''$ diameter $= 8 \times {\cdot}2485 = 1{\cdot}98$. — Table 15.

Testing for adhesion.

Stress $= \frac{{\cdot}568\,wL}{O\,d} = \frac{{\cdot}568 \times 2{,}200 \times 10\frac{1}{2}}{(8 \times \Pi \times \frac{9}{16}) \times 9} = 103$ lbs. square inch. — Para. 57.

This is near enough : larger rods would be found to give too high an adhesion stress.

b_r must not be less than $\frac{b_s}{6} = \frac{42}{6} = 7''$. — Para. 49.

For shear.

$s = \frac{{\cdot}568\,wL}{b_r\,d} = \frac{{\cdot}568 \times 2200 \times 10\frac{1}{2}}{7 \times 9} = 212$ lbs. per square inch. — Para. 54.

This is too high and to bring s down to 120, b_r must $= \frac{212 \times 7}{120} = 12{\cdot}33''$ or say 12.″

For rods in one row, width required $= 8 \times 1\frac{1}{2} \times \frac{9}{16} = 6\frac{3}{4}''$. — Para. 44.

$d_t = 9 \times (1\frac{1}{2} \times \frac{9}{16}) =$ say 10″.

At the supports a negative bending moment, equal to the central bending moment, must be provided for. As the width of the compression area at this point is only $b_r = 12''$, either the beam must be deepened or additional reinforcement provided or the two alternatives may be combined. To avoid difficulties in arranging the

9. *Reinforced concrete floor*—(contd.). *References.*

Secondary beams—(contd.).

rods, it will be convenient to use the same number and section of rods as used for the span.

Try $d = 10\frac{1}{2}''$.

$b_r\, d^2 = \frac{WL}{m} \times \frac{2}{3}$ or $m = \frac{2200 \times 10\frac{1}{2} \times 10\frac{1}{2} \times 2}{3 \times 12 \times 10\frac{1}{2} \times 10\frac{1}{2}} = 122$, corresponding to $p = 1\frac{1}{2}$ and $A_c = A_t$. Para. 40.

$A_t = \frac{p\,b\,d}{100} = \frac{1\frac{1}{2} \times 12 \times 10\frac{1}{2}}{100} = 1{\cdot}89$ square inches, so 8 rods $\frac{9}{16}''$ diameter, may be used top and bottom.

d_t at support may be made $11\frac{1}{2}''$.

Provision need only be made for the excess shear and half the tensile reinforcing rods may be turned up at 45°, at $\frac{L}{4} = \frac{10\frac{1}{2}}{4} = 2\frac{5}{8}'$ from the support.

$X = \frac{L}{2} - \frac{52{\cdot}8\,bd}{w} = \frac{10\frac{1}{2}}{2} - \frac{52{\cdot}8 \times 12 \times 9}{2200} = 5{\cdot}25 - 2{\cdot}59 = 2{\cdot}66'$. Para. 55.

$A_s = \frac{S}{10{,}000d} = \frac{6wX^2}{10{,}000d} = \frac{6 \times 2200 \times 2{\cdot}66 \times 2{\cdot}66}{10{,}000 \times 9} = 1{\cdot}03$ square inches.

Area of half tensile reinforcement $= \frac{1{\cdot}98}{2} = {\cdot}99$, which is near enough.

Main beams.

Span $\frac{49}{2} = 24\frac{1}{2}'$. Spacing $10\frac{1}{2}'$.

$$\left.\begin{array}{ll} \text{Superincumbent} & = 10\frac{1}{2} \times 150 = 1575 \\ \text{Slab} & = 10\frac{1}{2} \times \frac{4}{12} \times 150 = 525 \\ \text{Secondary ribs,} & = \text{say } 2 \times 100 = 200 \\ \text{Main ribs.} & = \text{say} = 400 \end{array}\right\} \text{2,700 lbs. foot. run.}$$ Table 1.

$$\left.\begin{array}{l} b_s = \frac{1}{3} \times \text{span} = \frac{1}{3} \times 24\frac{1}{2} \times 12 = 98'' \\ 15 \times d_s = 15 \times 4 = 60'' \\ \frac{3}{4} \times \text{spacing} = \frac{3}{4} \times 10\frac{1}{2} \times 12 = 94\frac{1}{2}'' \end{array}\right\} 60'' \text{ to be taken.}$$ Para. 49.

As the slab is thin compared to the minimum permissible depth $= \frac{24\frac{1}{2} \times 12}{18} = 16\frac{1}{3}''$, it is clear that the neutral axis will fall in the rib for any reinforcement over $\frac{1}{2}$ per cent. The beam is not too large, however, to be treated as a tee beam: if calculated as a rectangular beam, it would require 3 times as much steel for the same depth.

9. *Reinforced concrete floor*—(contd.). *References.*

***Main beams*—(contd.).**

Allowing for partial fixation: Para. 42.

$\frac{1\frac{1}{4}\,WL}{b_s\,d_s^2}=\frac{1\frac{1}{4}\times 2700\times 24\frac{1}{2}\times 24\frac{1}{2}}{60\times 4\times 4}=2{,}111.$ Para. 51.

For $p=\frac{1}{2}$ this corresponds to $\frac{d}{d_s}=5{\cdot}3$

or $d=5{\cdot}3\times 4=21{\cdot}2''$.

Equivalent to $\frac{21{\cdot}2}{24\frac{1}{2}\times 12}=\frac{1}{18{\cdot}9}\times$ span. Para. 49.

$A_t=\frac{p\,b\,d}{100}=\frac{\frac{1}{2}\times 60\times 21{\cdot}2}{100}=6{\cdot}36$ square inches or say 8 bars, each 1″ diam.
$=8\times{\cdot}7854=6{\cdot}3$ square inches. Table 15.

Testing for adhesion

Stress $=\frac{{\cdot}568wL}{O\,d}=\frac{{\cdot}568\times 2700\times 24\frac{1}{2}}{(8\times\pi\times 1)\times 21{\cdot}2}=70{\cdot}5$ Para. 57.
lbs. per square inch.
which is not too much and larger bars could be used.

b_r must not be less than $\frac{b_s}{6}=\frac{60}{6}=10''$. Para. 49.

Testing for shear

$s=\frac{{\cdot}568wL}{b_r\,d}=\frac{{\cdot}568\times 2700\times 24\frac{1}{2}}{10\times 21{\cdot}2}=177$ lbs. Para. 54.
per square inch.

This is too high and, to reduce s to 120, b_r must be not less than $\frac{177\times 10}{120}=14\frac{3}{4}''$.

Width required for rods in one row $=9\times 1\frac{1}{2}\times 1=13\frac{1}{2}''$. Para. 44.

Being an important beam a 2″ covering should be given or make $d=23\frac{1}{2}''$.

At the supports to provide for the negative bending moment, we may arrange to use the same number and section of rods as used for the span, and increase the depth to suit. Para. 52. Para. 42.

Try $d=23\frac{1}{2}''$.

$b_r d^2=\frac{WL}{m}\times\frac{2}{3}$ or $m=\frac{(2700\times 24\frac{1}{2})\times 24\frac{1}{2}\times 2}{14\frac{3}{4}\times 23\frac{1}{2}''\times 23\frac{1}{2}''\times 8}=132\frac{1}{2}$. Para. 40.

corresponding to $p=1{\cdot}8$ and $A_c=A$.

$A_t=\frac{1{\cdot}8\times 14\frac{3}{4}\times 23\frac{1}{2}}{100}=6{\cdot}24$ square inches, so 8 rods 1″ diameter may be used top and bottom. Table 15.

d_t at the supports may be made $25\frac{1}{2}''$.

Being an important beam the resistance of the concrete to shear will be neglected, but half the tensile reinforcement may be turned up at 45° at $\frac{L}{4}=\frac{24\frac{1}{2}}{4}=6\frac{1}{8}'$ from the support. Para. 55.

$A_s=\frac{S}{10{,}000d}=\frac{1{\cdot}5wL^2}{10{,}000d}\times\frac{1{\cdot}5\times 2700\times 24\frac{1}{2}\times 24\frac{1}{2}}{10{,}000\times 21{\cdot}2}$
$=11{\cdot}48$ square inches.

9. *Reinforced concrete floor*—(contd.). *References.*

Main beams—(concld.).

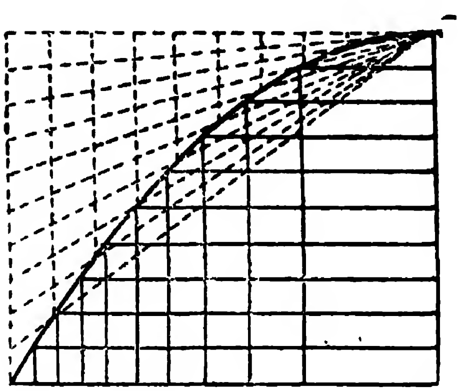
Area of half the reinforcing rods $=3{\cdot}15$ square inches, so they will take up $\frac{3{\cdot}15}{11{\cdot}48} = {\cdot}274$ of the stress and vertical stirrups may be provided for the remainder.

$A_s = \frac{S \times {\cdot}726}{11280\,d} = \frac{1{\cdot}5WL^2 \times {\cdot}726}{11280\,d} = \frac{1{\cdot}5 \times 2700 \times 24\frac{1}{2} \times 24\frac{1}{2} \times {\cdot}726}{11280 \times 21{\cdot}2} = 7{\cdot}4$ square inches.

Minimum number of stirrups $= \frac{24{\cdot}6}{d^2} \times \left(\frac{L}{2}\right)^2 = \frac{24{\cdot}6 \times 12\frac{1}{4} \times 12\frac{1}{4}}{21{\cdot}2 \times 21{\cdot}2} = 9$ Para. 56.

Double stirrups will be used, each stirrup to have 2 limbs. Section of steel required $= \frac{7{\cdot}4}{4 \times 9} = {\cdot}205$ or say $\frac{1}{2}''$ diameter, area ${\cdot}1963$ square inches. Table 15.

The spacing of the stirrups can be found



graphically as follows Draw $AB = \frac{\text{span}}{2} = 12\frac{1}{4}'$. On it erect a parabola to represent the bending moment. Divide BC into $N+1=10$ equal Parts and draw horizontals to the curve, from the ends of which perpendiculars are dropped to AB. The feet of these perpendiculars give the positions of the stirrups. The construction of the parabola is shown dotted. Additional stirrups should be given at distances not exceeding $d=21{\cdot}2''$ apart between the last stirrup on either side of the centre of the span.

9. *Reinforced concrete floor*—(contd.). *References.*

Column.

Load carried by one main beam across the building :

$$=49\times2700=132{,}300 \text{ lbs.}$$

of this $\frac{1}{5}$ is carried at each support and $\frac{3}{5}$, or 79, 380 lbs. by the column. Para. 58.

A circular hooped column may be used and, for the sake of appearance, its diameter may be made the same as the width of the main beam, $14\frac{3}{4}''$, the effective diameter being taken at $12\frac{1}{4}''$. Para. 59 (*b*).

d then $=\frac{12\frac{1}{4}}{16\times12}=\frac{1}{15\frac{2}{3}}$, × length and the column is a " short " one. Para. 58.

$$C=\frac{700\pi d^2}{4}(1\times\cdot14p)$$ Para 59 (*b*).

$$79{,}380=\frac{700\times\pi\times12\frac{1}{4}\times12\frac{1}{4}}{4}(1+\cdot14p).$$

$p=\frac{\cdot924-1}{4}$, a minus quantity.

The minimum re-inforcements may be given, ·8 per cent. in verticals and 1 per cent. in the helix.

$$A_1=\frac{p\pi d^2}{4\times100}=\frac{\cdot8\times\pi\times12\frac{1}{4}\times12\frac{1}{4}}{4\times100}=\cdot937$$
square inches.

6 rods, each $\frac{7}{16}''$ diameter, $=6\times\cdot1503=\cdot9018$ square inches will be near enough. Table 15.

The pitch of the helix may be taken as $\frac{d}{6}=\frac{12\frac{1}{4}}{6}=$ say $2''$.

$$A_h=\frac{r p^h d^2}{127\sqrt{\pi^2 d^2\times r^2}}=\frac{2\times1\times12\frac{1}{4}\times12\frac{1}{4}}{127\sqrt{(\pi\times12\frac{1}{4})^2\times(2)^2}}=$$
·0625 square inches.

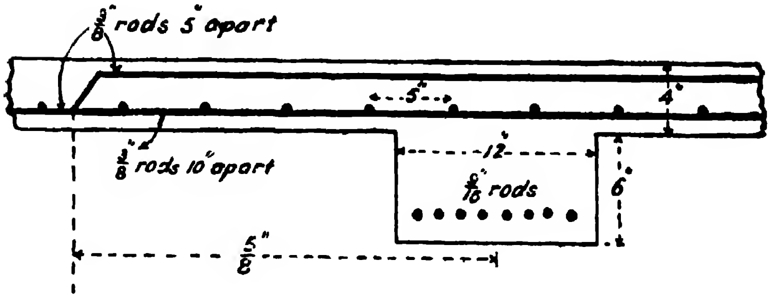
A $\frac{5}{16}''$ diameter rod, area ·0767, may be used and the pitch increased to $\frac{\cdot0767\times2}{\cdot0625}=$ say $2\frac{1}{2}''$. Table 15.

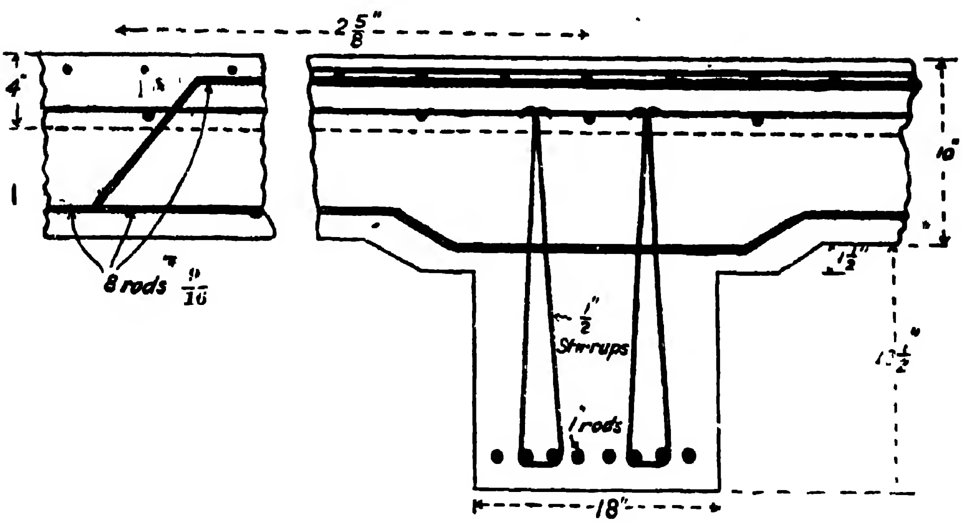
Column foundations.

$$\left.\begin{array}{l}\text{Load on column}=79{,}380\\ \text{Weight of do.}=16\times\\ \dfrac{\pi\times14\frac{3}{4}\times14\frac{3}{4}}{4\times144}\times150=2{,}840\\ \text{Weight of base}=\text{say }6{,}000\end{array}\right\}\begin{array}{l}82{,}220\text{ lbs.}\\ \text{on base}\\ 88{,}220\text{ lbs.}\\ \text{on soil.}\end{array}$$

Example 9. Reinforced concrete floor

Section through centre of secondary rib.





Section through main rib at junction with secondary rib

9. *Reinforced concrete floor*—(contd.). *References.*

Column foundations—(contd.). Area of base $= \frac{88,220}{1\frac{1}{2} \times 2,240} = 26 \cdot 25$ or $5\frac{1}{8}' \times 5\frac{1}{8}'$. Para. 61.

For height of base under column :

$$h = \frac{W - \cdot 25 \pi d^2 r}{\pi d s} =$$

$$\frac{82,220 - (\cdot 25 \times \pi \times 14\frac{1}{2} \times 14\frac{1}{2} \times \frac{1\frac{1}{2} \times 2240}{144})}{\pi \times 14\frac{1}{2} \times 60}$$

$= 28 \cdot 1''$ or say $30''$.

Bending moment in base

$= \frac{W}{8}(b - \cdot 85d) = \frac{88,220}{8}(5\frac{1}{8} \times 12 - \cdot 85 \times 14\frac{1}{2}) = 540,000.$

In the formula $bd^2 = \frac{WL}{m}$, the bending moment taken is $1 \cdot 5$ WL and so it may also be written thus : Para. 40.

$$bd^2 = \frac{\text{bending moment}}{m} \times \frac{2}{3}$$

Take a $12''$ strip and d as say $27''$, d_t being $30''$.

$$bd^2 = \frac{540,000}{m} \times \frac{2}{3}$$

$$m = \frac{540,000 \times 2}{12 \times 27 \times 27 \times 3} = 41 \cdot 2$$

corresponding to about $\cdot 4$ per cent.

$A_t = \frac{p\,b\,d}{100} = \frac{\cdot 4 \times 12 \times 27}{100} = 1 \cdot 296$

or $1''$ diameter rods, $\frac{\cdot 7854 \times 12}{1 \cdot 296} = 7\frac{1}{4}''$ apart in either direction and a similar rod across each diagonal. Table 15.

Stirrups of $\frac{3}{8}''$ steel may be given on every other rod at intervals not exceeding $27''$, this interval being decreased to about $7''$ at the centre.

The top of the foundation may be tapered off to $20''$ deep at the outer edges.

The column rods should be secured to the beam reinforcement at the top, and to the foundation reinforcement at the bottom.

9. *Reinforced concrete floor*—(concld.).

Table of results.

Slab 4″ thick, reinforced in both directions with $\frac{3}{8}$″ diameter rods, 5″ apart. Half the rods to be turned up at $2\frac{5}{8}$′ from the support and carried along the upper edge over the support to the same distance on the other side: additional rods to be given over the support, so as to preserve a spacing of 5″ along the upper edge.

Secondary ribs.—Rib to be 12″ wide and to project 6″ below the underside of the slab: the rib to be made $1\frac{1}{2}$″ deeper at the supports. Reinforcement to consist of 8 rods, $\frac{9}{16}$″ diameter; half the rods to be turned up at $2\frac{5}{8}$′ from the support and carried along the upper edge: the lower rods to be bent downwards corresponding to the increase in the depth of the rib at the support. For $2\frac{5}{8}$′ on either side of the support, 4 additional rods, $\frac{9}{16}$″ diameter to be given top and bottom.

Main ribs.—Rib to be $14\frac{3}{4}$″ wide and to project $19\frac{1}{2}$″ below the underside of the slab: the rib to be made 2″ deeper at the supports. Reinforcement to consist of 8 rods, 1″ diameter, half the rods to be turned up at $6\frac{1}{8}$′ from the support and carried along the upper edge; the lower rods to be bent downwards corresponding to the increase in the depth of the rib at the support. For $6\frac{1}{8}$′ on either side of the support, 4 additional rods, 1″ diameter, to be given top and bottom. Double stirrups of $\frac{1}{2}$″ steel to be given at the intervals shown in the calculations.

Columns.—To be $14\frac{3}{4}$″ diameter, reinforced with 6 vertical rods, ″ diameter, surrounded by a helix of $\frac{}{16}$″ steel wound round at a pitch of $2\frac{1}{2}$″. Vertical rods to be secured to the upper rods of the main beam and to the column foundation rods.

Column foundation.—To be $5\frac{1}{8}$′ square by 30″ high under the column, tapering to 20″ at the outer edges. Reinforcement to be provided on the lower edge, consisting of 1″ diameter rods, $7\frac{1}{4}$″ apart, both ways and a rod to be given across each diagonal. Stirrups of $\frac{3}{8}$″ steel to be given along alternate rods at intervals decreasing from 27″ at the outer edge to 7″ at the centre.

The arrangement of the steel is shown in the diagrams.

SECTION V.

Water-supply, Roads and Drains.

WATER-SUPPLY.

1. Estimates of the cost of a water-supply may be required in either of the following forms :— Estimates.

(*a*) Rough estimates as when computing the probable cost of a new cantonment. Conditions vary greatly, but when a supply can be obtained close at hand and filtration is not needed, the initial cost should work out to between Rs. 1-8 to 2 per gallon supplied daily: if the supply is obtained from a Municipality, the cost should not exceed half the above figures.

(*b*) Project estimate for submission to Government. This consists of a full report, calculations, specifications, plans and an approximate estimate of the cost of each subhead. It will usually be advisable to give estimates for pipes, fittings, and reservoirs in full detail, rough estimates for the pumping plant and plinth area rates for any buildings. If the supply is to to be obtained from a Municipality, a draft agreement should accompany the project.

(*c*) Detailed estimates for the various subheads of the sanctioned project.

2. A project will be arranged as follows :— Projects.

(*a*) List of references, with précis of the correspondence leading up to the preparation of the project.

(*b*) Report arranged thus—

(*i*) Brief history of case.

(*ii*) Nature of existing supply.

(*iii*) Quantity of water required.

(*iv*) Sources from which water can be obtained. Discuss the quantity available and the quality, stating whether purification is necessary, and whether the local medical authorities accept the scheme.

(*v*) Method of supply proposed: any alternative method should be discussed.

(*vi*) How the cost of water consumed by non-entitled persons is to be recovered: the method adopted in the adjoining Municipality should be stated.

Projects—(*contd.*).

(*vii*) Time required to carry out the work.
(*viii*) Initial and recurring cost of the scheme and the actual cost of water per 1,000 gallons.

(*c*) Specifications.
(*d*) Calculations for—

(*i*) Quantity of water required, giving separately the amount that will be consumed by non-entitled persons.
(*ii*) Pumps and rising main.
(*iii*) Capacity and stability of any reservoirs.
(*iv*) Distribution pipes.
(*v*) Maintenance charges, working expenses and rate for water.

(*e*) List of pipes and fittings required, lead for joints, etc.
(*f*) Explanation of rates.
(*g*) Estimate.

Quantity of water required.

3. The following allowances of water are authorised as maxima :—

	Gallons per diem.	
	In the plains.	In the hills.
Europeans . .	20	15
Indians . . .	8	5
Animals . . .	10	10

In addition special provision should be made for—

Bungalows 200-300 gallons per diem.

Messes 500 gallons per diem.

Soda water factories . . .	Amounts depend on local circumstances.
Workshops	
Dhobi ghats	
Grass and dairy farms . . .	
Road watering	
Drain flushing	
Allowance for expansion. . .	

The total daily supply for any cantonment should not exceed 15 to 25 gallons per head of the population.

Source of supply.

4. Water for a Cantonment can either be obtained from an existing Municipal supply or from an independent source. It may be advantageous for a City and a Cantonment to instal a joint supply or for Government to supply a Municipality. The joint ownership of a water-supply, however, usually gives rise to

difficulties and an arrangement by which one party buys water from the other is to be preferred.

5. The draft agreement with a municipality, from whom water is to be obtained, should clearly specify :— **Supply from a municipality.**

(*a*) Point at which water is to be supplied : usually the edge of the Cantonment. All pipes within cantonment limits should be the property of Government.

(*b*) Minimum pressure in the Municipal main at the point of supply. It may be more convenient for the Municipality to agree to fill a reservoir of a certain size in a certain position and at a certain level once a day or during specified hours.

(*c*) Maximum and minimum quantities to be supplied daily.

(*d*) How the water supplied is to be measured: where the meter is to be placed and who is to provide it.

(*e*) Rate of payment for water.

(*f*) Term of duration of the agreement.

6. Water is collected from catchment areas by channels to intercept springs and streams, which are thus led to collecting reservoirs. The catchment area should be acquired and fenced in. A design for a collecting reservior is given in plate XLII. **Sources in the hills.**

7. The yield of a spring should be tested at the driest time of year by means of a board with a notch placed across the stream : tables for ascertaining the yield in this manner are given in Molesworth's pocket book.

8. It may occasionally be necessary to supplement the supply by catching roof water in tubs, etc., and using it for washing and fire protection. Arrangements should be made for the first portion of a fall to run to waste.

9. River water is usually much polluted and requires to be purified before use. If below a village, the intake should be not less than 5 to 10 miles down-stream and should be situated at a point where the river is not likely to change its bed. Water from village ponds and canals should never be used for drinking purposes. **Rivers.**

10. The source of supply in the plains usually consists of wells sunk near or in the bed of a river or into any stratum containing subsoil water. Water may either be obtained from shallow wells where the water is found in the premeable subsoil immediately below the surface or in deep wells, where a permeable water bearing stratum underlying an impermeable bed is tapped. **Wells.**

11. As shallow wells are very liable to pollution from sewage, manuring of fields, etc., their sites should be chosen with great care and the surrounding area for a considerable distance inspected with a view to discovering possible sources of contamination. In **Shallow wells.**

the case of wells near rivers, training works may be necessary to prevent the river changing its bed.

Deep wells. 12. Deep wells are usually boreholes of only a few inches diameter, just large enough to take the necessary tubing for the lift pump. But sometimes a well several feet in diameter is sunk for part of the way, usually to an impermeable stratum, and then a bore hole is sunk down to the water bearing stratum. The upper lined portion is then used as a storage reservoir.

13. Artesian wells are those in which the level of the water in the water bearing stratum being higher than that of the ground at the mouth of the well, the water rises in the bore hole near to or above the level of the ground.

Galleries. 14. It has been found in many cases that the driving of horizontal galleries below the water level is more effective in increasing the yield of wells than deepening them, as the area for collection of water is thereby increased, and there is a greater likelihood of striking the fissures through which the largest volumes of water are moving.

Yield of wells. 15. The yield of a well may be tested by pumping until the water level has been depressed to the safe maximum head: the speed of the pump should then be adjusted so that the amount of water withdrawn is equal to the amount entering the well. The yield should be tested at the driest time of the year and enquiries should be made locally regarding the lowest known water level.

16. There are often practical difficulties in carrying out a pumping test on a well and accurate results may be obtained by means of recuperation tests. If the normal water level in a surface well, area A square feet, is depressed by pumping H feet and, if, as the well recuperates, it takes t hours for the water to rise to a level h feet below normal water level, then the specific capacity of the well or the yield in cubic feet per hour under a head of 1 foot will be :—

$$\frac{K}{A} = \frac{1}{t} \log. \frac{H}{h} \times 2{\cdot}303.$$

$\frac{K}{A}$ will be constant as long as the velocity of inflow does not exceed the "critical" velocity, below which limit the surrounding soil is not disturbed. The velocity of inflow in feet per hour, v, and the capacity of the well, γ, in cubic feet per hour are given by

$$v = \frac{K}{A} h \text{ and } q = Av = Kh.$$

The results of several tests should be plotted in a curve with $\frac{H}{h}$ as ordinates and t as abscissæ: if the value of $\frac{K}{A}$ is not constant it is an indication that the critical velocity has been exceeded.

Further information on this subject will be found in Punjab Public Works Department paper No. 63 of 1909. The maximum yield will be obtained from a well when it is worked continuously without exceeding the critcial velocity. It has been ascertained that the safe head for wells in fine sand is 5 to 7 feet, the yield being about 16 gallons an hour per square foot of percolation area and the value of $\frac{K}{A}$ about $\frac{1}{2}$. In coarse sand or gravel the value of $\frac{K}{A}$ may be as high as 1 and the safe head can then be increased. In clayey soils the value of $\frac{K}{A}$ is only about $\frac{1}{4}$. The yield having been ascertained, a certain "factor of safety" should be applied, depending on the considerations mentioned in the next paragraph, for ordinary purposes a factor of safety of 2 to 4 should be taken, but it may be remarked that wells have been known to yield eventually only one-tenth of their original supply. **Yield of wells—(contd.)**

17. A well from which large quantities of water are regularly drawn will gradually produce less water. One reason for this is that the subsoil round the well is acting like a filter and, like all filters, tends to get clogged: a point will eventually be reached when the supply becomes fairly constant. Other reasons for the supply becoming diminished are that wells are placed too close together or that the general level of the subsoil water becomes lowered. When water is drawn from a well, the level of the subsoil water in the immediate neighbourhood becomes depressed: the area thus affected is termed the "cone of depression" and usually is a circle of 200 to 600 feet radius. Wells should be sited so that the removal of water from one well does not affect neighbouring wells. As to whether the subsoil water level is likely to be permanently lowered by continuous pumping, a careful consideration of the geology of the neighbourhood is necessary with a view to ascertaining the area of the catchment that supplies the subsoil water and the rate at which it gets replenished.

18. Water may be drawn from a number of wells by either of the following methods:—

(*a*) The wells may be connected by adits or pipes at some point below the lowest water level: this is a difficult operation, as the water has to be kept under by pumping.

(*b*) The wells may be connected to one another or to a central sumph by siphons: the siphons may give trouble.

(*c*) A suction pipe may lead from a suction chamber near the pump to each well: this is the most usual method.

(*d*) A pump may be placed in each well, power being supplied from a central station.

Percolation tubes.

19. In alluvial soils water may be obtained by means of percolation tube wells. The tube well is so designed that water is freely admitted to the interior through openings that are fine enough to exclude sand : to attain this object copper wire or tape is wound on a steel framework at close intervals so as to leave narrow slits, or a wire mesh is employed : the wire (" Ashford " patent) or tape wound patterns, are the best and on account of the greater strength and the fineness of the apertures, they can safely be used under a considerable head without sanding up. The tubes are made in lengths of 5 to 6 feet and of 5-inch to 10-inch diameter. Joints are made by means of a divided ring bound with wire and rendered water-tight with lead wool: a cap for closing the base is connected in the same way.

A trial boring should always be sunk in order to ascertain the positions of the water bearing strata. A plain tube, whose diameter is large enough to admit the tube well is sunk in the ordinary way. The tube well is then placed in position and the plain tube withdrawn. Where the tube well passes through strata that do not produce water, plain pipes are used. The suction pipe of the pump can be connected directly to the tube well.

The yield will of course depend on the pumping head, the nature of the subsoil and the water available. At Amritsar, where the conditions are particularly favourable, a 10-inch well sunk to a depth of 95 feet yields continuously 558 gallons a minute, while a 5-inch well yields 120 gallons a minute. Ten inch wells can be spaced 500 feet apart : 5-inch wells 200 feet apart. It may be taken that area for area a tube well is 20 times as efficient as an ordinary well.

The cost of an " Ashford " tube well per foot run is, 10-inch diameter Rs. 14 and 5-inch diameter Rs. 8. The cost of the outer tube, which can of course be used again, is Rs. 11 per foot for 13-inch tubes and Rs. 3-4 per foot for 7-inch tubes : these rates apply to " cressed and swelled " tubing, which is suitable for the purpose. The cost of sinking varies from a few annas to Rs. 3. per foot depending on the nature of the soil.

Well sinking in hard soil.

20. The excavation for the well will be marked out to the requisite diameter, which will be two feet larger than that of the outside of the steining, and will be continued vertically downwards until the water level is reached, care being taken to keep it of the same diameter throughout. A shaft 4 feet in diameter will then be sunk to ascertain whether a water bearing stratum has been reached, which will give a permanent supply of at least 10 feet of water. Should any sandy or shaly soil be met with, the side, of the excavation must be cased with planking. Rock must be

carefully blasted out, the charges used being first approved by the officer in charge of the work. **Will sinking in hard soil —(*contd.*).**

21. The curb will consist of sound heartwood of shisham, mulberry, or other hard wood, cut to the requisite curve, dove-tailed, dowelled, and fastened with bolts, straps and trenails. It will first be put together on the surface of the ground, and after being passed by the officer in charge of the work, will be taken to pieces, tarred, and lowered down to the bottom of the well, where it will be put together and firmly fixed and levelled. Curbs may also be made of reinforced concrete, steel or cast iron.

22. Six 1″ vertical iron rods, rising above the curb as high as the depth of water proposed, will then be passed through the curb at equal intervals, and be secured below with nuts, to tie down the steining under water to the curb. These tie rods being secured so as to keep them vertical, the building of the steining on the curb will be commenced round them.

23. The steining will be of brickwork or rubble masonry laid in mortar. If of brickwork, it will be $1\frac{1}{2}$ feet thick for wells not exceeding 40 feet in depth. For deeper wells the steining must be thicker. If of rubble masonry, the steining will be 2 feet thick for wells 40 feet deep: the stones will be roughly dressed with the hammer to the requisite shape, and the work executed otherwise as specified for coursed rubble masonry in mortar. The steining will usually not be plastered or pointed: if however, the exclusion of surface water is a matter of importance, the steining should be lime or cement plastered.

24. On the completion of a height of steining equal to the proposed depth of water, a circle of flat iron $3'' \times \frac{1}{2}''$ will be laid on the top and firmly secured to the iron tie rods. Weep-holes $6'' \times 3''$ for the admission of water are to be left at intervals in the steining as may be directed: in the case of shallow wells, these weepholes should be omitted, as they admit contaminated surface water. The brickwork or masonry will then be allowed to stand until the mortar has set, when the sinking of the cylinder may be commenced, the permission of the officer in charge of the work having first been obtained. The earth below the water level will be excavated and the cylinder loaded, care being taken that it descends evenly and vertically.

25. All soil and rubbish will be removed from under the curb until the sole has an even surface, and as the steining descends, it will be carried up to the ground surface, the vacant space round the steining being filled in and thoroughly rammed as work proceeds. For a depth of 8′ to 10′ from the surface, the steining will be surrounded with puddled clay.

Well sinking in hard soil—(*concld.*).

26. Round the well a brick or terrace floor 6″ wide will be laid with a slope to a drain round the outside of it. The steining will be corbelled out to support that portion of the flooring which rests over the filling, so as to prevent any settlement, and will be raised 2′ above the floor level to prevent water flowing back into the well. The well may be also provided with a cover to prevent contamination.

Well sinking in sandy soil.

27. In many localities in India the water bearing sand has small layers of kankar and clay interspersed in it at irregular depths. These form very useful platforms on which to rest the curb forming the bottom of the well. It is desirable therefore to make a few borings with a sand pump at the site of a proposed well to ascertain whether any of these layers exist at a suitable depth, before deciding on the exact spot at which to commence sinking.

28. The excavation, laying of curb, and building up of steining will be carried out much as described for hard soil, but below water level the sand may be excavated by a Bull's Dredger, and layers of clay met with by a native "jham."

29. The well should be sunk if possible until the curb rests on a layer of clay, which is well below the water level in the driest season of the year. If this layer of clay is only a small mass in the middle of water bearing strata, it may be pierced in the centre, when the surface of the sand underneath will gradually assume the form of an inverted cone of such an area that the water will come away from it just slowly enough not to take any sand with it. The layer of clay forms a platform above this hole, on which the well rests securely, without silting up or giving any trouble. If, however, the layer of clay is of large extent it must not be pierced unless it can be ascertained that good water exists below it, or the whole of the supply may be lost.

30. When such a layer of clay cannot be found at a reasonable depth, the curb must rest on sand, and the steining be supported by friction only. In this case any rapid drawing of the water will cause the well to silt up, or it may create a hole underneath the curb into which the latter, with part of the steining, may fall, thus ruining the well.

31. On the first signs of a well going crooked during sinking, the dredger should be worked on the opposite side of the well to that towards which it is inclined. In extreme cases the "jham" may be used instead of the dredger, as it stirs up silt less and allows a deeper hole to be made on one side. The well may also be weighted on one side by rails, etc.

Impounding reservoirs.

32. Whenever the minimum rate of yield of a source of supply is less than the demand, the excess of the demand over the supply

must be furnished by storing up water during periods of greater yield in impounding reservoirs. The ordinary method in India of attaining this object is to construct a dam of earth or masonry across a valley. Impounding reservoirs—(contd.)

33. The section of the site for the dam and its construction requires great care and text-books on the subject should be consulted. The following data are given as a guide to the preparation of rough estimates and to gauge the merits of various alternative sources of supply.

34. The rainfall statistics of the district should be consulted in order to ascertain the mean average annual rain falling on the catchment area and the recorded departures from this figure noted. It may be assumed that the percentage of the rainfall that will reach the reservoir will vary from 25 per cent. for flat localities with sandy soil to 65 per cent. or more for steep rocky hill sides.

35. The site of the dam should be chosen with a view to economy in construction: the depth to impervious soil must be ascertained. If possible the situation of the reservoir should be such that pumping can be dispensed with.

36. The outlet of the dam should be well above the bottom, due allowance being made for silt depositing. A waste weir should always be given.

37. The capacity of the reservoir will be the quantity of water contained between the waste weir and the outlet levels. From this amount a percentage should be deducted for percolation, evaporation and allowance for dry years. In places where the rainfall is precarious the maximum capacity should be sufficient for at least two years without replenishment. The mean daily evaporation amounts to ·2 inches: the maximum may be as high as ·56 inches.

The catchment area must be protected from contamination and all villages on it must be acquired. It is possible that compensation will also have to be paid for existing water rights.

38. Samples of water from the source of supply it is proposed to adopt should be analysed by the Divisional Sanitary Officer, who will arrange for their collection. If necessary the water will have to be purified either by settlement or filtration or both. Purification.

39. Solid matter in suspension may be removed either by storage for a certain period or by allowing the water to pass very slowly through large tanks. For absolute quiesence three tanks at least are needed: one empty for cleaning, one filling and one emptying: the outlet should be through a floating arm. For continuous flow, long narrow tanks are needed with baffle walls to prevent a current forming: a small catch-pit fitted with a sludge drain Settling tanks.

to catch the heavier matters in suspension should be given. The continuous flow method entails less loss of head, but is usually more expensive. The amount and form of settlement necessary must be ascertained by experiment. It may often be convenient to add alum to the water before settling *vide* paragraph 45.

Filters. 40. Filters are rarely required in the hills, but are usually necessary in the plains. It may often be more economical to obtain water near at hand requiring filtration rather than to make use of a more distant though purer source. The usual methods of filtration adopted in India are ordinary sand filters or Jewell filters. It will often be necessary to settle the water before filtering it. Generally it will be advisable to locate the filters at the pumps, as this economises supervision and avoids the necessity for pumping wash water.

Sand filters. 41. The filter bed consists of a water-tight reservoir divided into compartments and filled with filtering media to a depth of 5 feet: spare units must be allowed for cleaning. The floor is gently sloped to an outfall drain leading to the clear water well; on it will be placed bricks on the flat followed by a layer of 6″ clean gravel 1″ gauge, two or three layers of finer gravel 3″ to 4″ thick, each layer rather finer than that the last: finally 1 foot of coarse and 2 feet of fine clean sand. Ventilators will be provided from the centre of the filter to allow the air displaced by the water to escape.

42. The water will be gently introduced on to the surface by means of a pipe discharging vertically upwards. For the first day or two the water passing through the filter should run to waste as no purification will have taken place. Gradually a gelatinous film will form just below the surface and efficient filtration will result. The rate of filtration should be kept uniform at about 1 to 2 gallons per square foot per hour, depending on the fineness of the sand and the quality of the water: to keep this rate, the filtering head, *i.e.*, the difference in level between the water on the filter bed and in the clear water well will have to be gradually increased. The depth of water on the filter bed should be not less than two feet.

43. Cleaning will be effected by removing the top surface to a depth of ½″ to 1″ and washing it in special sand washers. Filters should be filled from below with filtered water to a depth of 3″ above the surface before being put into use again.

44. The clear water well should be of sufficient capacity to equalise the demand, say 2 or 3 hours supply. If water has to be pumped the capacity will depend on the number of hours that the pumps are at work during the day.

45. A Jewell filter plant consists of three essential portions :— **Mechanical filters.**

(a) the coagulating basin, where $\frac{1}{4}$ to 3 grains per gallon of sulphate of alumina is added and settlement allowed for 6 to 12 hours.

(b) the filter tank proper on to which the settled water is passed by gravity or under pressure. The filter tank is filled with pure quartz sand resting on gravel. A strainer system at the bottom is employed to collect the filtered water and to distribute the washing water.

(c) the clear water basin.

The effect of adding sulphate of alumina to the water is to produce a flocculent precipitate of hydroxide of alumina, which settles down, entangling and carrying with it many of the impurities contained in the water. A certain percentage of the precipitate is carried forward to the filter on the surface of which it settles as a gelatinous film, which plays the same important part as the organic film that forms on the surface of the ordinary slow sand filter.

In Jewell gravity filters the filtering head commences at 3 feet and is gradually increased to 12 feet: the rate of filtration is 125 million gallons per acre per day. The filters have to be washed every 12 to 24 hours by forcing filtered water in a reverse direction through the sand under a head of 40 feet and at the same time operating a revolving rake: for the first 10 to 15 minutes after restarting, the filtered water is run to waste as good results are not obtained until the gelatinous film has formed.

The pressure type of filter is supplied in cylindrical drums of 12 to 78 inches diameter. In some cases primary settlement is dispensed with and the raw water is forced straight through the filter.

The gravity filter gives much better results than the pressure filter, which should only be used in cases where a high degree of purification is unnecessary, *e.g.*, for washing water, etc.

At Cawnpore the Puech Chabal system of filtration has recently been installed. The principle is to run the raw water through a series of course filters, the first full of $1\frac{1}{2}$ inch gauge granite, the last of coarse sand, before passing it on to the slow sand filter beds. No chemicals or sedimentation tanks are required, while the sand filters work more rapidly and can run without cleaning for from 6 to 12 months.

46. The water will be conducted from the source by gravity or pumping, either to service reservoirs or direct to the points of supply. With a pumped supply or a very long gravity main the provision of a reservoir is always necessary to guard against break- **Method of supply.**

downs. If the rising main passes through the area where water is required it may be conveniently used as the supply main. Double pipe lines are not economical but may sometimes be necessary to guard against breakdowns.

Pumping plant. 47. The type of pumping plant to be adopted will be decided by the Inspector of Machinery at Army Head-quarters, who will require the following information, which should be given in the project :—

(*a*) Full report on any power that may be available, *viz.*, electricity, water power, existing boilers, etc. In the case of electrical power the source of the supply should be given also its nature and the price per unit: if to be obtained from a company, etc., it should be stated what, if any, electrical apparatus, etc., they are prepared to supply and maintain.

(*b*) The price of first class steam coal delivered at the pumping station, stating the colliery from which obtained. Also the brands and prices of oil or liquid-fuel obtainable, how stored and what arrangements can be made for delivery. Where coal and oil are very expensive the price of wood fuel should be given and if possible its calorific value.

(*c*) A sketch of the surroundings giving the site proposed for the pumping station. If near a river the site must be chosen so that the floor is at least one foot about highest flood level.

(*d*) Quantity of water required daily.

(*e*) Numbers of hours it is considered that the pumps should work. For small plants 8 hours pumping daily is usually allowed and this permits of expansion when necessary. For large steam plants continuous pumping is more economical.

(*f*) Vertical and horizontal distance in feet from ground level at the engine room to maximum and minimum water levels in the well, etc.

(*g*) Vertical and horizontal distance in feet from the ground level at the engine room to the floor level at the reservoir.

(*h*) Depth and capacity of reservoirs.

(*i*) Height of station above sea level.

Suction pipes. 48. It is an advantage for the water to gravitate to the pumps under a small head. The maximum suction lift permissible is ·7 (L—F), where L is the theoretical suction lift, 33 feet at sea level and one foot for every 1,000 feet above sea level, and, F, the

friction in the suction pipe. With small pumps the suction lift should be kept at least 5 feet below the figure thus obtained. The suction pipe should be as short as possible and contain few bends: it should be laid with a slight falling gradient from the pump to the source of supply. The velocity of flow should not exceed 2 feet per second. There should be a strainer at the lower end: the sum of the areas of the holes in the strainer should not be less than twice the area of the pipe. Above the strainer a foot-valve is required: this is a reflux valve to allow the pipe to be filled from a bypass from the rising main. If the suction pipe is at all long, an air vessel is required on it near the pump to equalize the water pressure and the flow of water. When the rise and fall of water in the stream is such that the maximum suction lift is likely to be exceeded, it may be necessary to form a sumph fed by an adit taken from a point higher up on the stream. **Suction pipes—(contd.).**

In certain cases it may be necessary to obtain water from a series of wells placed some distance apart so that the infiltration of adjoining wells may not interfere with one another. Long lengths of suction pipe will be required to such wells: these pipes should each be fitted with a sluice valve and led to a common suction chamber, fitted with an aircock at the top and a bypass to the rising main. Where long lengths of suction pipe are used it is essential to successful working to have all joints water-tight and only flanged or screwed joints should be used.

Rising main.

49. The rising main will be fitted with a reflux valve close to the pump, to relieve the pump from the pressure due to the column of water in the main; on long mains it is necessary to give reflux valves at intervals to restrict the loss of water in the event of a burst. Above the reflux valve a branch pipe with a sluice valve on it should be given to enable the main to be washed out when necessary. A sluice valve is usually provided on the main above the reflux valve to enable the latter to be removed for repairs. Below the lowest reflux valve a pressure relief valve is essential, if either a sluice valve is given on the main or a self-closing valve at the reservoir: in certain types of pumps a relief valve is needed on the pump itself. With pumps, where it is necessary to start with a light load, a bypass with a cut-off valve is given from the rising main below the reflux valve to the washout pipe below its sluice valve. A 2″ bypass piped fitted with a cut-off valve should be given round the reflux valve in order to fill the boiler. Air and scour valves may be necessary, *vide* paragraphs 70 and 71. If a meter is needed at the pumping station, it should be placed on the suction side of the pump, where the lower pressure is less likely to damage it.

Cost of pumping plant.

50. The pump horse-power required for a plant is found thus—

$$P.H.P. = \frac{W \times (H+F)}{33,000}$$

where W=weight of water lifted per minute in lbs., equivalent to the flow in gallons per minute multiplied by 10.

H=height to which water is raised in feet, equivalent to the difference in level between the strainer on the suction pipe and high water level in the reservoir.

F=friction in suction pipe and rising main.

The P. H. P. will vary between 55 to 80 per cent. of the brake horse-power depending on the type of pump used and the B. H. P. will amount to about 80 per cent. of the indicated horse-power.

In every case two pumping sets each capable of doing the whole work should be allowed for.

The initial cost of the installation may be taken at—

Rs.				H. P.
2,000	per P. H. P	for small plants above		5
1,500	do	for plant of about		10
1,000	do.	do.	do.	20
750	do.	do.	do.	40
600	do.	do.	do.	80

The working expenses per P. H. P. hour may be taken roughly at 8 annas for small plants of 10 H. P. and under: 4 annas for medium size plants working 8 hours a day and 1 anna for large plants working continuously; these figures include all charges for staff coal, oil, etc., but nothing for repairs, depreciation and interest on capital outlay.

51. The most economical combination of pumping plant and rising main requires consideration. The diameters of rising main with a velocity between 1 and 3 feet per second should be taken and the friction calculated. The P. H. P. required for each size of main can then be calculated; rough out the cost of the main and the plant for each size of main: work out the annual cost made up of the working expenses *plus* 9 per cent. on the cost of the plant and 6 per cent. on the cost of the pipes for depreciation repairs and interest on capital outlay.

Service reservoirs.

52 Service reservoirs are required to balance the fluctuations in the supply and demand throughout the day and to provide a reserve in case of fire or breakdowns. Their capacity should not as a rule exceed one day's supply for elevated tanks and gravity supplies. With a long rising main and pumping head of over 100 feet, 2 to 4 days' storage should be allowed according to circum-

stances. If more than two days' storage is allowed, the quality of the water, if filtered, is likely to deteriorate. Where the rising main is used for supply or where water is obtained from several sources the capacity of the reservoir may be safely reduced to half a day's supply. Service reservoirs—(*contd.*).

53. The reservoir should be sited on ground high enough to maintain sufficient head in all the distribution pipes and should if possible be centrally situated. Where barracks are situated at great differences of level or are very far apart, it may be economical to provide more than one reservoir. In some cases it may be advisable to provide a main reservoir at ground level and a small subsidiary elevated tank to supply buildings close to the reservoir.

54. Reservoirs may be entirely below ground, with masonry or concrete walls, which need not be thicker than is required to withstand the earth pressure: or they may be built entirely or partly above ground of reinforced concrete or brickwork, steel, wrought or cast iron: or they may be elevated on a base of masonry or steel framework. A circular reservoir is the most economical, but difficult to roof. An above ground reservoir is easier to repair and clean out. Reservoirs should always be roofed and ample means of access and ventilation provided. A description of a reinforced brickwork tank was issued with D. G. M. W.'s memorandum No. 3282-B of 19th August 1904. It is often convenient to line reservoirs with some kind of continuous bitumen sheeting in order to prevent leaks.

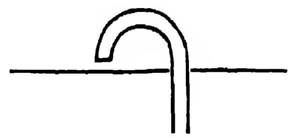
55. A bypass should usually be provided round the reservoir, which should be divided into two compartments, to facilitate cleaning. An external indicator worked by a float should be provided to show the depth of water. In the case of a one day reservoir fitted with a bypass two compartments are not as a rule necessary.

56. The inlet pipe should discharge at the top of the reservoir over the side wall. It should be fitted with an ordinary sluice valve for each compartment and a self-closing equilibrium valve worked by a float. If no equilibrium valve is provided a man must be told off to watch the r[illegible]oir and to signal to the pumping station when the reservoir is ful[illegible].

57. The outlet should be at least 6″ above floor level so as to be above any sediment that may have been collected. It should be fitted with a strainer, the aggregate area of the holes in which should be at least double the area of the pipe. A sluice valve should be fitted on the outlet pipe from each compartment. The outlet in any reservoir should be kept $2\frac{1}{2}$ feet at least below the

Service reservoirs—(*contd.*).

minimum water level or air will be sucked into the pipes. To avoid wasting storage space the outlet can be made thus—



58. The floor should be gently sloped to a shallow sumph containing the wash out pipe: a valve will be fitted outside the reservoir on the wash-out pipe from each compartment. An overflow pipe of slightly larger capacity than the inlet pipes should be provided and connected to the wash-out pipe beyond the valve.

59. The following table gives the costs of certain reservoirs and filters :—

Station.	Type of reservoir or filter.	Capacity gallons.	Cost.	Cost ; per cent gallons.
			Rs.	Rs.
Allahabad .	Steel, circular, 60′ diam. × 11½′ deep ; raised 36′ on masonry base.	200,000	35,000	175
Bangalore .	(*a*) Partly above ground, masonry, masonry roof, two compartments each 235′×137½′×10 feet depth of water.	4,000,000	1,11,000	28
	(*b*) Jewell filters, 6 sets, filters per day.	3,000,000	3,00,000	100
	(*c*) Sand filters, 3 sets, 2 in use at a time, filters per day.	1,000,000	95,000	95
Bareilly . .	Steel tank 45′×45′×11′, raised 34 ft., corrugated iron roof, one compartment.	140,000	36,000	257
Dagshai . .	(*a*) Pumping reservoir, stone, 2 compartments. (Daily consumption 35,000 gallons).	55,000	10,000	182
	(*b*) Service reservoir, stone, 2 compartments.	50,000	10,500	210
	(*c*) Bazaar reservoir, stone, 2 compartments. (Supplied intermittently : taps open at stated hours).	70,000	12,000	171

Service reservoirs—(*concld.*).

Station.	Type of reservoir or filter.	Capacity gallons.	Cost.	Cost per cent gallons.
			Rs.	Rs.
Jabalpur, Ridge .	(*a*) Reinforced brickwork, above ground, 4 compartments, each 26′ diam. × 10′ deep. Tiled roofs on corrugated iron.	160,000	11,000	69
	(*b*) Reinforced brickwork, above ground, 4 compartments, each 29′ diam. × 10′ deep. Tiled roofs on corrugated iron.	200,000	14,000	70
Jabalpur, Factory.	Underground. Stone masonry: 4 compartments.	280,000	18,500	66
Peshawar . .	6 Filter beds, each 75′×36′: 5 in use at a time.	720,000	69,000	96
Risalpur . .	Steel reservoir, circular, 45½′ diam. × 11½ deep (10′ to overflow), raised 47′ above ground on masonry. Corrugated iron roof. One compartment.	100,000	32,000	320
Saugor . .	Above ground, masonry, 2 compartments.	40,000	3,300	83
Solon . .	Storage reservoir, 2 compartments, stone, (Service reservoirs exactly similar).	75,000	4,500	60
Subathu . .	(*a*) Cantonment reservoir, steel, raised a few feet on a masonry base, 2 compartments.	71,000	33,000	465
	(*b*) Bazaar reservoir, 2 compartments stone.	126,000	22,500	179
Quetta . .	(*a*) Old cantonment reservoir No. 1, two tanks, masonry, below ground, corrugated iron roof, each.	376,000	21,500	57
	(*b*) Old cantonment reservoir No. 2: two tanks as above, each.	407,000	21,500	53
	(*c*) New cantonment reservoir: two tanks, as above, each.	240,000	19,000	79
	(*d*) Staff College reservoir: two tanks as above, each.	24,000	4,000	166

Calculations for reservoirs.

60. (*a*) Cylindrical reservoirs. The bursting pressure, P. in lbs. at a depth H feet below the surface of the water in a reservoir of diameter D feet is found by the formula :—

$$P=\frac{62\cdot5\ H.D.}{2}\ \text{per lineal foot.}$$

For the thickness of steel plates to resist this pressure

$$t_p=\frac{62\cdot5\ H.D.}{2\times12\times11{,}200}.$$

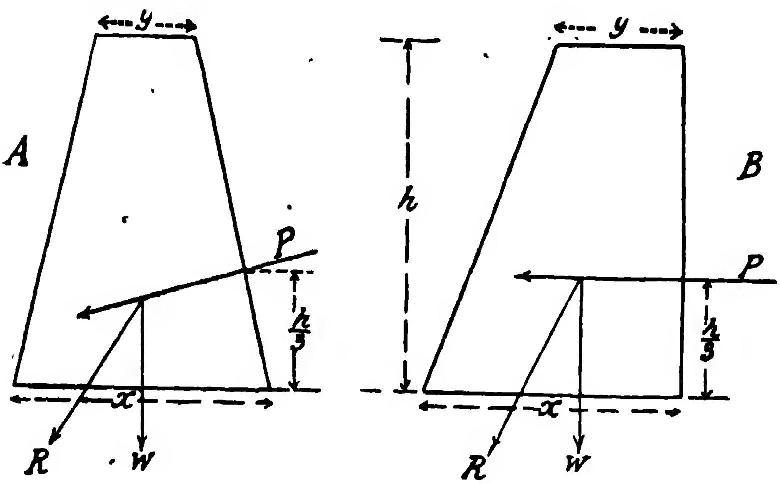
For reinforced brickwork or concrete tanks, if A is the area of the circumferential steel required in a depth of 1 feet.

$$A=\frac{62\cdot5\ H.\ D.}{2\times11{,}200}$$

(*b*) Reservoirs walls of masonry. The resultant pressure R of W, the weight of the masonry, and P, the water pressure, must not pass outside the centre third of the wall.

$$P=\frac{62\cdot5\ H^2}{2}\ \text{and acts at ⅔rds of the depth.}$$

W=weight of masonry in 1′ length of wall, acting at the centre of gravity.



The thickness of wall required may be determined graphically by trial and error, or by means of the following formula :—

(1) Wall A, $x^2+2xy.\dfrac{g-1}{2g+3}-\dfrac{4h^2+y^2}{2g+3}=0$

(2) Wall B, $x^2+xy-y^2-\dfrac{h^2}{g}=0$

where g=specified gravity of the masonry **Calculations for reservoirs—(*contd.*).**

$$=\frac{\text{weight per cubic foot of masonry}}{\text{weight per cubic foot of water}}.$$

(*c*) Stability against sliding. The resultant horizontal force, P in this case, must not exceed μ times the resultant vertical force, W in this case, where

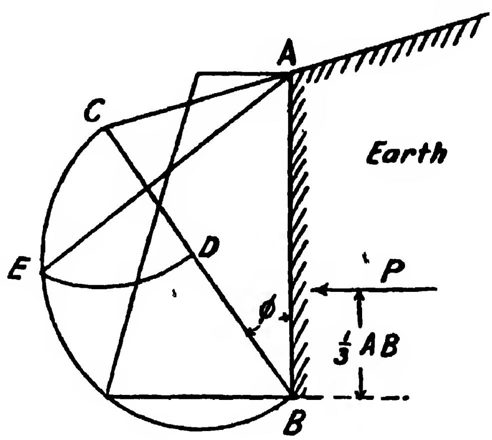
μ =·7 for dry masonry.
=·51 for masonry on dry clay.
=·33 for masonry on wet clay.

(*d*) Reservoirs with arched roofs. The thrust of the roof must be combined with P and the resultant so obtained combined with W to obtain R.

(*e*) Stability against earth pressure at the back. Draw B C at an angle to A B, a vertical line immediately at the back of the wall: continue the natural slope of the earth to cut B C in C: draw AE perpendicular to BC cutting a semicircle erected on BC at E. make CD=CE ; then

$$P=\tfrac{1}{2}w\,(BD).$$

where w is the weight per cubic foot of the soil. If the back of the wall slopes, A B is drawn vertical from the foot of the wall. ϕ, the angle of repose of the soil,=36° for dry sand : 39° for gravel : 47° for dry earth : 54° for moist earth.



61. The distribution mains should be arranged to run through the areas where the greatest supply is required by the most direct routes. It is an advantage, but by no means a necessity, to connect mains at their extremities. All pipes should be designed to deliver the supply in 8 hours. The velocity in mains should not exceed the following : 4″—3 f. s. : 6″—4 f. s. : 10″—5 f. s. : 16″—6 f. s. **Distributions mains.**

62. The velocity in service pipes should not exceed 7 feet per second, otherwise they are likely to suffer from water hammer. The delivery from a tap should not be less than 5 gallons a minute, double this being allowed for large baths : it may be assured that one tap in a small and two in a large building will be turned on at once. No service pipe should as rule be less than ¾ inch diam., but with high pressures ½ inch diameter may be used. The head at the end of a pipe open full bore is *nil*, but to allow overcoming **Service pipes.**

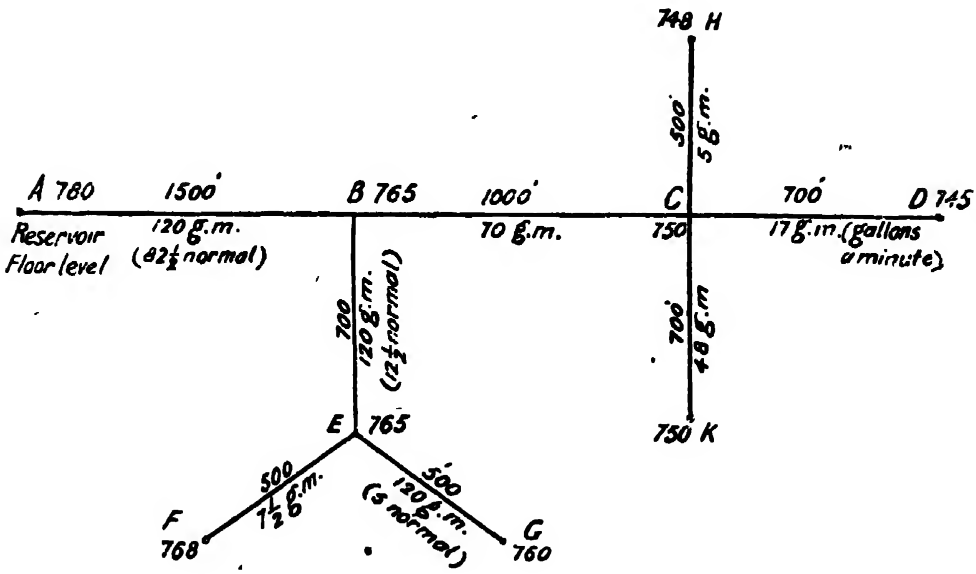
the friction in small pipes in a building, at taps, etc., a residual head not less than 5 feet should be allowed at a tap, which may be taken as usually equivalent to 10 feet at ground level just outside the building.

Fire service.

63. For fire hydrants a flow of not less than 120 gallons a minute is necessary: it should be assumed that all valves in the neighbourhood will be closed so as to give the maximum delivery at the hydrant. For very important building two hydrants should be provided and the main calculated for a flow of 240 gallons a minute. For barracks in India a fire service is generally unnecessary.

Calculations for pipes.

64. A diagram, which need not be to scale, should first be drawn, showing the lengths of pipes, the points of supply and the levels at all connections, thus



The supply in gallons per minute required at each point should then be worked out both for fire and ordinary service and entered on the diagram, thus—

F 50 Europeans at 20 gallons . =1,000
200 Indians at 8 gallons ... =1,600 } 3, 600=7½ g.m.
100 animals at 10 ,, ... =1,000

G Bungalow 300 gallons .....=5 g.m. (minimum permissible).
Stackyard 120 gallons a minute for fire service.

H 50 Indians at 8 gallons .... = 400 : 5 g.m.

Calculations for pipes—(contd.).

K 1,000 Indians at 8 gallons .. =8,000 ⎫
500 animals at 10 gallons .. =5,000 ⎬ 48 g.m.
Dhobi ghats .... =10,000 ⎭

D 1,000 Indians at 8 gallons .. =8,000 : 17 g.m.

The sizes of the pipes required can then be worked out in the following form, making use of the chart: fire service, if provided, will determine the sizes of pipes necessary in some cases, but the pressures available must be based on the normal supply :—

Point.	Length of Pipe in feet.	Flow in gallons per minute.	diameter of Pipe.	Loss of head by friction.	R. L. of H.M.G.	R. L. of Ground.	Residual head in feet.	REMARKS.
				Fire service (if required).				
A					800	..	..	Reservoir.
	1,500	120	6″	4·3				
B					795·7	765	30·7	
	700	120	4″	13·7				
E					782	765	17·0	
	500	120	4″	9·8				
G					77·2	790	12·2	
				Normal service.				
A					800	..	..	
	1,500	82½	6″	2·2				
B					797·2	765	32·2	
	1,000	70	4″—300′ 3″—700′	2·3 21·0				
C					773·9	750	23·9	
	700	17	2″	15·9				
D					758	745	13·0	
B					797·2	765	32·2	
	700	12½	4″	·2				
E					797	765	32·0	
	500	7½	1½″	8·6				
F					788·4	768	20·4	
C					773·9	750	23·9	
	500	5	1½″—400′ 1″—100′	3·4 6·7				
H					762·8	748	14·8	
C					773·9	750	23·9	
	700	48	3″	10·9				
K					763·0	750	13·0	

Calculations for pipes—(*contd.*).

The above calculations are not quite correct but afford a simple method of attaining the correct result. For instance at F, the residual head with a flow of 7½ gallons a minute is given as 20·4 ft. If the tap at F is 5 ft. above ground and 5 ft. of head is required to overcome resistence in the tap, internal piping, etc., the actual residual head will be 10 ft. only.

The following formula (Fanning's) has been used for the chart on the next page :—

$$H = \frac{G^2 \times m \times L}{5{\cdot}5767 \times d^5}$$

where H=loss of head in feet. G=discharge in gallons per minute.

L=Length in feet. d=internal diameter in inches.

m is a coefficient having the following values :—

$$\left.\begin{array}{l} \tfrac{1}{2}'' \text{ pipe } {\cdot}016 : \tfrac{3}{4}'' \text{ pipe } {\cdot}0155 \quad . \quad . \quad . \\ 1'' \text{ pipe } {\cdot}015 : 1\tfrac{1}{4}'' \text{ pipe } {\cdot}01475 \quad . \quad . \quad . \\ 1\tfrac{1}{2}'' \text{ pipe } {\cdot}0145 : 2'' \text{ pipe } {\cdot}014 : 2\tfrac{1}{2}'' \text{ pipe } {\cdot}0135 \end{array}\right\} \text{foul pipes.}$$

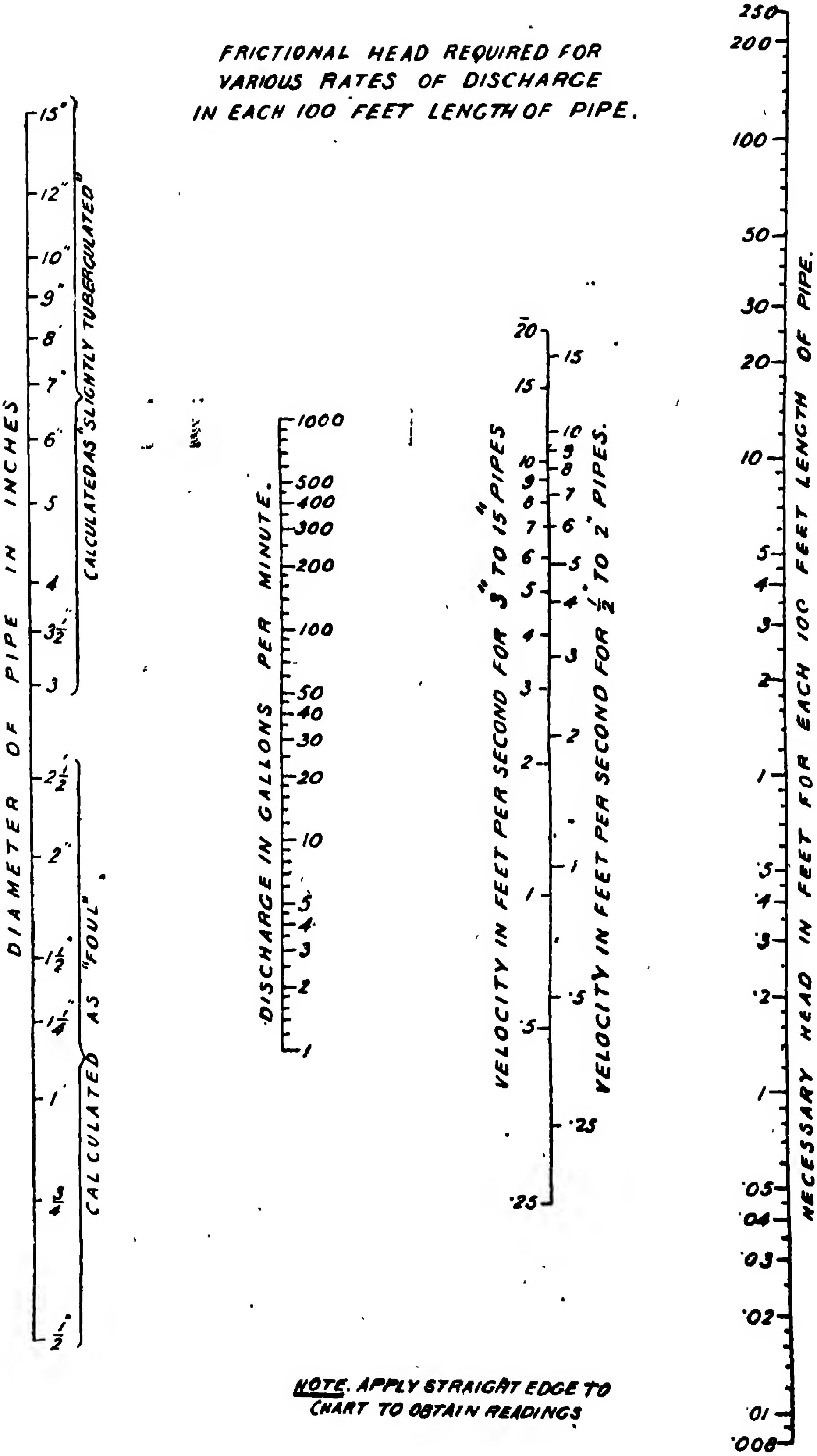
$$\left.\begin{array}{l} 3'' \text{ pipe } {\cdot}00862 : 3\tfrac{1}{2}'' \text{ pipe } {\cdot}008435 \quad . \quad . \\ 4'' \text{ pipe } {\cdot}00825 : 5'' \text{ pipe } {\cdot}007985 \quad . \quad . \\ 6'' \text{ pipe } {\cdot}00772 : 7'' \text{ pipe } {\cdot}00752 \quad . \quad . \\ 8'' \text{ pipe } {\cdot}00733 : 9'' \text{ pipe } {\cdot}00719 \quad . \quad . \\ 10'' \text{ pipe } {\cdot}00706 : 12'' \text{ pipe } {\cdot}00680 \quad . \quad . \\ 15'' \text{ pipe } {\cdot}00646 \quad . \quad . \quad . \quad . \quad . \end{array}\right\} \text{Slightly tuberculated pipes.}$$

It may be useful to note that

Pressure in lbs. per sq. inch=head in feet × ·433

1 Cubic foot a second=375 gallons per minute.

FRICTIONAL HEAD REQUIRED FOR
VARIOUS RATES OF DISCHARGE
IN EACH 100 FEET LENGTH OF PIPE.



NOTE. APPLY STRAIGHT EDGE TO CHART TO OBTAIN READINGS

The following formula may prove useful when it is desired to ascertain for a length L of pipe, with an available head H, what portion X may be a larger diameter than the remainder, the friction per 100 feet in X being f_1 and in the remainder f_2. Calculations for pipes—(*contd.*).

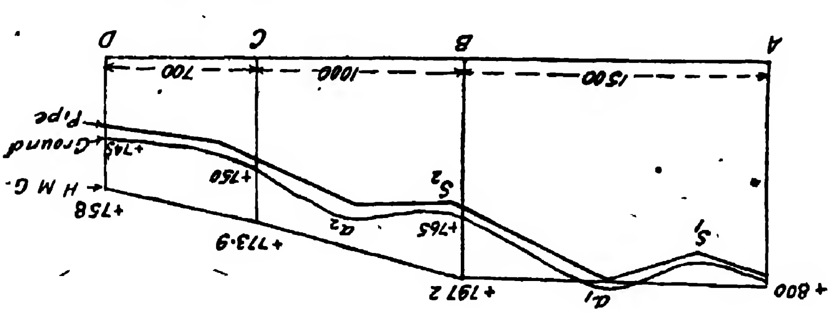
$$X=\frac{Lf_2-100H}{f_2-f_1}$$

Thus if we have a pipe 500 feet long, delivery 5 gallons a minute, head available 16 feet or 3·2 feet per cent. : a 1″ pipe would require 6·6 ft. per cent., and a $1\frac{1}{4}$″ pipe 2·2 feet per cent.

$$X=\frac{(500\times6{\cdot}6)-100H}{6{\cdot}6-2{\cdot}2}=387 \text{ ft.}$$

Thus 387 feet of $1\frac{1}{4}$ inch and 113 feet of 1 inch pipe would be wanted.

65. Levels should be taken along the proposed pipe line and a longitudinal section drawn. The pipe line can then be put in at depths, to the top of the pipe, from 18″ to 10 feet or so below the surface, depending on the nature of the soil : where severe frost occurs the pipe should be kept at least 3 feet under ground. Frequent or abrupt changes of direction or grade are to be avoided The hydraulic mean gradient (H.M.G.) for the mains should then be drawn : an illustration on a small scale is given for the pipe A B C D in paragraph 63 : Pipe line.



Air valves would be required at a_1,a_2 and scour valves at s_1, s_2. The pipe line should, if possible, be kept well below the H.M.G. and in any case should not rise more than 6 or 7 feet above it. It must be remembered that above the H. M. G. the pressure will be negative and water can only flow by symphonic action. Incrustation or other causes may lower the H.M.G. bringing it down so low that symphonic action will cease altogether. Thus, if, in the diagram above a_1 at the pipe happened to be 30 feet or more above a, on the H.M.G., the deliveries at B, C, etc., would not be as calculated. Water would flow to a_1 provided it were lower than A : the flow, however, would be small owing to the little fall available and the

Pipe line (contd.).

amount having been ascertained, the calculations for the H.M.G. for the rest of the pipe would have to start at a_1.

Pipes.

65A. Cast iron or steel pipes should be used for diameters of 3″ and upwards and galvanised wrought iron pipes for diameters under 3″. Cast iron pipes of the thicknesses usually made should be guaranteed to safely resist a head of 300 feet and wrought iron pipes 700 feet. Steel pipes are made to any thicknesses required: when ordering, the head of water they have to withstand should be specified. Steel pipes are more economical than cast iron pipes, where the cost of carriage is considerable, but their life is variable and depends on the nature of the soil in which they are laid and which should aways be ascertained before steel pipes are used. They should be dipped in Angus Smith solution, wrapped in Hessian cloth and re-dipped: if the wrapping is damaged in transit, it should be renewed and the outside re-coated with Angus Smith solution.

66. Angus Smith solution consists of pitch, to which 5 per cent. of linseed oil has been added, heated to a temperature of 300° F: every pipe must attain a temperature of 300° F before removal from the vessel containing the solution.

67. Cast iron pipes are supplied with flanged, turned and bored or spigot and socket joints: the latter have lead joints. Flanged joints are required at a meter, valve, etc., which may have to be removed for repairs, or sometimes for suction pipes where a close joint is wanted to prevent air being sucked in or where special lengths are required at reservoirs: a blind flange should be specified as a rule and holes drilled where required. For long straight lengths of pipe under ground, turned and bored pipes should be used, but at every tenth pipe a lead joint is necessary to allow for expansion and contraction: as a plain spigot will not fit a turned socket, 80 per cent. of the pipes should be turned and bored, 10 per cent. turned spigot and plain socket and 10 per cent. plain spigot and turned sockets. It may often be convenient to order all pipes turned and bored and to cut off the spigot of every tenth pipe so as to form a lead joint. For pipes exposed to the sun or when the line is very sinuous spigot and socket joints should be used throughtout.

68. On a steep hill side the cumulative weight of the pipes may be so great as to injure the joints: to remedy this the pipes should be anchored at intervals to masonry pillars.

Valves.

69. To regulate the flow of water sluice valves should be used on cast iron pipes and screw down stop-cocks on wrought iron pipes. A valve should be given at each connection with a main and on the main itself at intervals of about 1,000 feet. Sluice valves should be

ordered with tail pieces, on one side flanged and spigot, on the other side flanged and socket. Valves—(contd.).

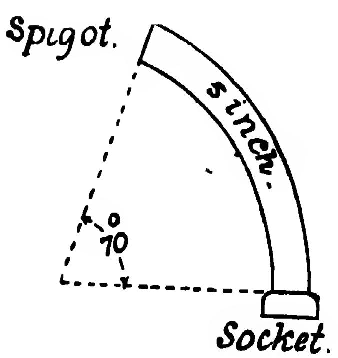
70. At every low point on the main, where silt is likely to collect, a bottom connection with a valve should be given to allow the pipe to be scoured out. At dead ends a scour valve is also necessary, unless a stand post or tap happens to be situated there. Scour valves.

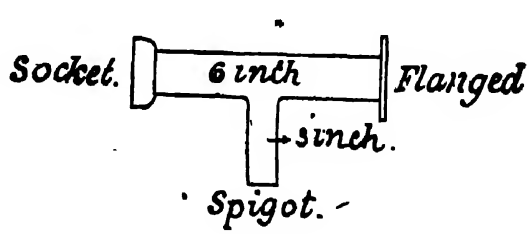
71. At every high point on the main an air valve should be given. In long lengths of pipe it is often advisable to provide air valves at sharp horizontal bends, as well as at all high points. When the pipe is under considerable pressure a single or double cast iron valve is necessary: a 2″ valve will do for pipes up to 10″ diameter: the pressure in the pipe and its diameter should be specified. The valve should be fitted on a connection with a stop-cock. Air valves.

72. When the pipe line lies quite a short distance below the hydraulic gradient, the most satisfactory form of air valve is a ½″ diameter pipe carried up to within a foot of the hydraulic gradient: the pipe may be covered by a cap but the passage of air should not be interfered with.

73. Where a pipe rises above the hydraulic gradient, it is useless to provide an air valve. A short connection with a stop-cock should be given at the highest point and a valve on the main lower down. To release the air, the valve should be closed and the stop-cock opened for a few minutes.

74. When ordering bends, tees, etc., a drawing should be given showing exactly what is required, thus Special pieces.





For upright pipes in reservoirs, etc., duck foot flanged bends should be used at the base.

75. In the hills it is often desirable to use break pressure tanks in order to keep the pressure in the pipes within safe limits. The capacity of the tank need not be more than 500 gallons: it is fitted with a ball valve at the inlet: the outlet should be at least 2½ feet below the inlet. Pressure reducing valves may also be used. Break pressure tanks.

Connections. 76. A connection to an empty main is made by means of inserting a nipple, a short length of pipe with a male screw throughout. With small diameter pipes the nipple will project into the pipe and interfere with the waterway: to obviate this, special pipes with cast iron bosses should be used. Special expansion nipples can be obtained which render the joint more secure. If it is necessary to make a connection to a pipe under pressure, a special main drilling apparatus must be used and a ferrule with a plug inserted. Special regulating ferrules can be obtained, by which means the supply can be controlled. If a cast iron pipe has to be connected to a large main and no tee is available, a special saddle piece must be fixed on to the main at the point of connection. Where a length of pipe has to be introduce d into a wrought iron system, it is customary to employ a "connector" a short piece of pipe, one end of which has screw thread cut on it of sufficient length to take the collar: the joint is made tight with spun yarn and a back nut.

Standposts, taps, etc. 77. Standposts, taps, etc., will be required as follows:—

(*a*) $\frac{1}{2}''$ screw down bibcocks in bathrooms, pantry and cook house sinks and one in the verandah of barracks and dinning halls occupied by British troops.

(*b*) $\frac{1}{2}''$ waste not taps, in lavatories in the proportion of 1 tap to every 2 basins.

(*c*) $\frac{3}{4}''$ screw down bibcocks for large baths: usually the taps are supplied with the baths.

(*d*) $\frac{3}{4}'$ shower baths worked by a galvanised iron chain in private ablution rooms.

(*e*) $\frac{3}{4}''$ waste not taps, for standposts in the lines of Indian troops, bazaars, for servants' quarters attached to officers and subordinates' quarters.

(*f*) ball cocks in a separate closed compartment for water troughs. There should be no outlet from the water troughs.

(*g*) Wheel valves for cartwatering standposts: these standposts should be about 500 yards apart on roads that have to be watered. There should be a platform of stone setts large enough to take the cart.

In all cases suitable drainage arrangements must be made to carry away waste water.

Fittings. 78. Ample provision should be made for fittings for wrought iron pipes such as tees, round elbows, bends, reducing sockets, plain sockets, reducing tees, nipples, back nuts and plugs.

Cisterns. 79. Cisterns should be used as little as possible and should be of small size, as the water in them is likely to get foul: if possible

they should not be used for drinking water. They are required for intermittent supplies or when the pressure to a house is very high in order to act as a break pressure tank to relieve the pipes, or when the pressure is very low, so that there may always be a supply of water available. They are fitted with a ball valve.

80. Meters are of three types :— Meters

(a) Venturi, expensive but accurate: should only be used for large supplies and where skilled supervision is available.

(b) Positive, where water enters and leaves measured vessels. The best patterns are the Kennedy, Worthington general service, Beck's, Kent's standard and uniform patterns. Positive meters are best for domestic purposes.

(c) Inferential, where the passing water revolves a fan or turbine. The best patterns are Siemens, Worthington disc, and Tylor's Inferential meters are cheaper than the positive patterns and should be used for water in large quantities as dhobi ghats, etc.; they are generally satisfactory except when there is liable to be air in the pipes.

If the water is hard, the working parts of the meter should be of delta metal and the interior of the cast iron body should be coated with silica enamel.

81. The loss of head in positive meters is often considerable and they should always be ordered of the same size as that of the pipes to which they are to be fitted. If plenty of head is available it is advisable, in the case of inferential meters, to use a smaller meter than the size of the main: for instance a 6″ meter may be permitted with a 9″ main. Every important meter should have a dirt box and two valves one on either side, to facilitate its removal for repairs and cleaning: a bypass with a valve should be given round the meter or duplicate meters should be used: sometimes the bypass is dispensed with and a flanged pipe inserted in the place of the meter. Meters should be provided on distribution pipes to bazaars, sets of lines, etc., in order to detect and prevent waste.

82. The pipes will be lined up on one side of the alignment of the trench with ends touching, and sockets facing the direction from which the water will flow. Pipe laying.

In the case of pipes less than 3″ diameter, they may be placed at suitable intervals in stacks of not more than 25 pipes.

83. The bed of the trench will be truly and evenly dressed throughout from change of grade to change of grade. The spoil will be thrown on the opposite side of the trench to the pipes.

Pipe laying —(*contd.*).

84. All road crossings will be excavated half at a time, the second half being commenced after the first has been refilled over pipes laid. Road metal will be stacked on one side ready for subsequent re-use.

85. Before the pipes are laid, the bottom of the trench, if the soil is loose, will be well rammed, so as to form a solid bed on which the pipes will rest. Any soft places or black cotton soil met with during excavation should be excavated and filled with sand or rammed earth. Where blasting is necessary, the rock will be removed to a depth of at least 6″ below formation level, and the bed of the trench made up with sand or rammed earth. Care must be taken that there is no rock at bends for the pipe to rest against and thereby interfere with its free expansion and contraction. In mains under high pressure it may be necessary to embed all bends in concrete, in order to resist the thrust.

86. In crossing marshy sites the grade can be preserved by sinking slabs of stone or slate vertically throught the soft soil (if of no great depth) to a firm foundation and adjusting their tops as required, a concave notch forming a seat for the pipe. If steel pipes are exposed in long lengths, it is necessry to tie down the pipes at intervals.

87. The minimum depth of trench is to be 1′ 6″ *plus* the diameter of the pipe to be laid: under roads the depth should not be less than 3′. The minimum width at the top will be :—

For pipes 3″ to 6″, 18″ wide.

7″—10″ ..... 24″

12″—20″ .... 36″

88. When a trench is left open at night a chowkidar must be left in charge and a lamp placed at each end and at intervals along the trench. If necessary a barrier will be put up to prevent danger to passengers.

89. The bottom of the trench must be carefully graded. A series of horizontal bars, fixed on supports on either side of the trench, should be first levelled off to the correct grade. The invert of the trench will then be a fixed depth below the bars and can be easily checked. These sight rails should be not more than 300′ apart. No pipes will be laid until the grading of the trench has been checked and passed by the officer in charge.

90. Before laying, pipes will be examined for flaws and cracks, and will be thoroughly cleaned inside. Cracked pipes are to be cut with diamond pointed steel chisels, at least 6″ beyond the visible extremity of the crack.

91. The pipes will be laid with sockets facing the way the water will flow. Work will be commenced from the end furthest from

the source of supply, and upwards from valves and other specials. Several sections can be laid at the same time if it is necessary to work quickly. When pipes are laid on brick pillars, the socket should be well clear of masonry to allow the lead joint to be caulked.

92. Lead required for jointing should be supplied departmentally, otherwise, as it is an expensive item, contractors will starve the joints.

93. The open end of the last pipe is to be securely closed, on ceasing work for the day, with a strong wooden plug fitting the socket of the pipe.

94. The pipes will be carefully lowered into the trench and supported on earth in the centre, pits being left at the joints for leading. The spigot will be truly centred in the socket with steel wedges. The socket will then be caulked with not less than three laps of white spun yard, twisted into ropes of uniform thickness, packed up to the shoulder of the socket and leaving the correct depth for the lead. The minimum depths will be :— Laying spigot and socket pipes.

	inch.	inch.
For pipes	3 to 4	1
	5 to 8	$1\frac{1}{4}$
	9 to 12	$1\frac{1}{2}$
	14 to 18	$1\frac{3}{4}$

The laps of yarn must be all rather longer than the circumference of the socket; no make up pieces are to be allowed.

95. To lead the joints, first clear them of earth and pebbles. Then make a wrapper of spun yarn worked up with clay having the consistency of putty. This should be about 3″ wide and $\frac{3}{4}$ inch thick and 4″ longer than the circumference of the joint. Wrap this round the joint with the overlap on top, and make a hole in it to admit of the molten lead being poured in. This must be thoroughly liquid and the ladle for pouring it into the joint should hold a little more than is required for one joint. The filling should be one operation and the lead should be poured in quickly. Then strip off the wrapper and use it for the next joint, and so on.

96. When a section of a few hundred feet is leaded, the caulking will be put in hand. Each gang of caulkers should consist of at least four blacksmiths, and for large diameters the numbers should be increased. One of these must be a good smith. Place the men in line, the worst man in front, and let them proceed to caulk a joint each with a caulking iron and blacksmith's hammer. Every 15 minutes move the gang on 1 joint, thus each joint receives an hour's caulking, and is worked on by all four smiths. The lower portion of the joint requires especial attention and supervision.

Laying spigot and socket pipes—(contd.).

In wet situations it is advisable to use lead wool for the joints.

97. Should it be necessary to work quickly, several sections can be laid at the same time. Where their ends meet, they may be joined by a sleeve joint, or by cutting the final pipe to length, when the spigot can be slipped into its socket by lifting one or two of the pipes laid loosely on eitherside of the last joint to be laid,

Laying turned and bored pipes.

98. The turned and bored rings of the spigot and socket of each pipe are to be thoroughly cleaned and polished. The polished rings will be wiped round with a clean cloth dipped in water, or any solution specified before being fitted in position.

99. The pipes are driven home using the next pipe to be laid swung on ropes as a ram. This must be done with great care, particularly with pipes of small calibre, the sockets of which are apt to split if the spigot is driven in too far. It is advisable to use a wooden block to protect the end of the pipe being driven.

100. No external joints will be given, except at points difficult of subsequent access such as under railways, drains, etc., which will be leaded as an additional precaution.

Laying W. I. pipes with screw and socket joints.

101. All piping will be at a minimum depth of 18″ below the surface of the ground. Care must be taken that branches do not project unduly into the water way of the pipe to which they are connected.

102. The pipes will be laid truly to grade. Pipes may be bent through angles not exceeding 45°, but piping of more than 2″ diameter cannot be bent to any great extent. Bends must not be made at joints, or the screw threads will be damaged.

103. The joints are made by screwing the end of the pipe to be laid into the socket of the pipe last laid by means of pipe tdngs. Care must be taken to prevent the pipe already laid turning during the operation. Sections of piping may be joined by screw collars.

104. Pipes should always be laid winding in the trench to allow for contraction when the cold water is run in. For the same reason at a curve the pipe should not bear against the inner side of the trench.

Laying mild steel pipes.

105. Steel pipes are solid drawn or lap welded and sometimes have special joints. At Murree, steel rings carefully turned were shrunk on to the ends of the pipes, one end being tongued and the other grooved. A rubber washer was placed in the groove, and the tongue of the next pipe was then fitted into it, and heavy cast iron collars fixed behind the steel rings. The joint was then secured by screwing up six cross bolts, passing through holes in the cast iron collars. Such connections are only required under a very heavy pressure and for such cases fibre washers have been found to be less perishable than rubber.

106. To provide for expansion and contraction, sleeves made from locomotive buffer tubes were placed over the ends of tubes after the steel rings had been removed. A deep lead filling was run in and caulked. To prevent this blowing out segments of steel were placed round the tubes, bearing against the lead at the ends of the sleeve. Over these segments the ordinary cast iron collars were placed, and drawn together by the longitudinal bolts until the segments pressed firmly against the lead at either end of the sleeve. This joint worked well under a head of 1,400 feet. The idea was that contraction and expansion took place by the steel tubes sliding in the lead jackets. For spigot and socket pipes lead wool is to be preferred for the joints when there is any difficulty in using molten lead. Laying W. I. pipes with screw and socket joints—(*contd.*).

107. When the pipe line has been laid, the joints will be tested by turning on the water. This may be done by closing cross sluice valves and thus producing rams. This should be continued in each section for two days. If any leakage occurs in lead joints, they will be remade, if in turned and bored joints, the joints are to be leaded. Testing pipes.

108. After the pipes have been tested the trenches are to be filled in with earth laid in 6″ layers, watered and rammed. All extra earth and rubbish is to be removed by the contractor on the completion of the work. Great care must be taken that the space underneath the pipes is properly filled in, and that the sockets are adequately supported. Any sinkage from defective laying within three months of completion will be made good by the contractor at his expense. Filling in trenches.

109. In laying these the faces or raised strips must be thoroughly cleaned, and when bolting up after the specified insertion has been placed in position, care must be taken to tighten the flange bolts gradually and evenly all round. When washers of rubber or other material are used, they must be held in position by loops of thin twine through the bolt holes before the flanges are brought together, care being taken that the washer is not allowed to encroach in the least on the bore of the pipe. Chalk rubbed upon the faced strips of a flanged joint before inserting the washer facilitates subsequent removal, by preventing the latter from adhering to the metal faces. Leaks through bolt holes of flanged joints can be stopped by the insertion of lead washers under the head or nut of the bolt as may be required. Laying flanged pipes.

110. The covers and glands of all valves are to be removed, packing adjusted, spindles and gates examined, and the whole refitted in free and perfect order before being sent to site. In setting, the valves must be carefully adjusted as nearly vertical Setting of valves.

as possible in both directions before the lead joints of the connecting tailpieces are made.

Maintenance of water-supplies

111. For a period of two years after completion, the whole line of main should be carefully patrolled daily by chowkidars, to discover subsidence of the ground, signs of leakage, etc. After this period the main lines need not usually be inspected more than once a week.

112. The whole area supplied with water should be divided into convenient divisions, each division being placed in charge of a chowkidar or Inspector. This man's duties are :—

To inspect every tap and line of main in his daily district.
To exchange taps found defective.
To see that standposts and platforms are kept clean.
To open the scour valves periodically.
To report breakages, or ill-usage of taps, and waste of water.
To oil the valve spindles and see that the valves are in working order.
He should know the position of every valve in his district and to what extent the closing or opening of the valves affects the general distribution; also how, in case of fire, to arrange the valves so that the whole supply of water can be directed to a certain locality.

By judiciously transferring these inspectors from one district to another, they gradually learn the positions of the taps, valves, mains, etc., in the whole station.

113. Each standpost or tap should be numbered and a map should be maintained and carefully kept up to date, showing the positions and numbers of standposts, taps and valves.

Copies, preferably ferrotypes of this map, should be provided for the Cantonment Magistrate, Deputy Commissioner, and Staff Officers or others, who may have to refer in correspondence to the water-supply.

Standposts require repainting every third year. To avoid obliteration of the numbers and the expense of re-numbering, it is advisable to have the numbers cast on the standpost covers by the makers.

114. When carrying out the distribution scheme of a water-works, careful record should be kept of the postion of every pipe, valve, etc., showing sizes of pipes, depths below ground level, and the accurate positions of all valves, hydrants, etc., with reference to some permanent building. Neglect of these precautions causes endless trouble sometimes, as after a lapse of years and with frequent changes of officers and subordinates, valves and sometimes long lengths of pipe are apt to get lost.

115. Registers posted daily should be carefully maintained to show :— Maintenance of water-supplies—(*contd.*).

Quantity of water in reservoirs received from head works, pumped, used, and so on.

Diagrams showing the consumption, etc., posted monthly or weekly are very useful for easy reference.

Where pumping machinery is used, registers should be kept to show the boiler and engine in use, the quantity of water raised, number of engine strokes and of fuel and other stores used. These are necessary to keep a constant check on the operation and to enable the return required by D. G.'s Circular letter No. 281-E of 1st June 1905 to be filled in.

116. The recurring charges incurred in connection with water supplies are divided into Maintenance Charges and Working Charges, both debitable to M. W. estimates. Maintenance and working charges.

(*i*) Maintenance charges include;

(*a*) the repair and renewal of such works as buildings, mains, tanks, standposts, connections and fittings to Government buildings;

(*b*) the repair and renewal of machinery;

(*c*) the pay of establishment engaged in supervision and care of plant or buildings.

(*ii*) Working charges comprise expenditure on—

(*a*) Payments for water supplied by municipalities or other local bodies;

(*b*) pumping and working expenses, including fuel, oil, sand or gravel, etc., for filtering purposes; shelter and upkeep of animals employed on the supply of water; salaries of engine house staff.

(*c*) the supply, fixing and repairs of meters (except those on mains, which form an integral part of the water-supply installation) and other means of controlling the distribution or of measuring the supply of water;

(*d*) pay, housing and all incidental charges in connection with establishment clerical or otherwise engaged in the supervision and check of the distribution of water and in the collection of water rates or taxes.

117. All persons in cantonments, not entitled to a free supply of water, will pay a tax for water-supply on the annual rental value of the buildings, or pay for quantity consumed according to meter measurement. Separate payment will be made by the Cantonment Water-tax and cost of water.

Water-tax and cost of water—(*contd.*).

fund for all water used for Cantonment purposes such as dhobi ghats, road watering, etc.

The rates are fixed by the Cantonment authorities, and should be such as will give a fair return on the outlay and cover maintenance and working expenses on the proportion of the water supplied to non-entitled persons, *vide* D. G. M. W.'s Circulars Nos. 17-B of 1903 and 25-B of 1904.

118. The total annual cost of water will be taken as the sum of :—

Interest $3\frac{1}{2}$ per cent. on total initial cost.

Maintenance charges (exclusive of any addition for supervision charges, but including renewals and repairs and sinking fund.) — $5\frac{1}{2}\%$ on cost of machinery. $2\frac{1}{2}\%$ on cost of pipes. 2% on cost of buildings.

Working expenses.

The cost of water per 1000 gallons is obtained by dividing the above by the number of thousand gallons consumed in the year.

The annual cost of water supplied to non-entitled persons is—

$$\frac{\text{No. of gallon supplied to such persons}}{\text{Total annual consumption}} \times \text{Total annual cost.}$$

Table of Weights of cast Iron pipes.

Diameter of pipe.	Weight in Cwt. per 100 feet including sockets and Flanges.			Weight of lead per joint : lbs	Weight of yarn per joint : lbs.
	Spigot and socket.	Turned and bored.	Flanged.		
3"	12·2	12·3	12·1	2·22	·24
3½"	14·0	14·1	14·3	2·4	·27
4"	15·7	15·8	16·4	2·77	·3
5"	23·1	23·3	23·5	5·73	·64
6"	27·3	27·5	28·0	6·64	·75
7"	35·8	36·1	38·1	7·66	·86
8"	41·2	41·6	43·0	9·71	1·1
9"	51·5	51·9	54·3	10·87	1·24
10"	63·0	63·4	65·3	12·03	1·37
12"	75·3	75·9	80·3	14·1	1·67
15"	103·6	104·6	107·2	20.77	2·22

All pipes are supplied in 9′ lengths excluding sockets.

Depth of lead in spigot and socket pipes is $1\frac{1}{2}''$ for $3''$—$4''$ pipes: $1\frac{3}{4}''$ for $5''$—$7''$ pipes: $2''$ for $8''$—$12''$ pipes and $2\frac{1}{4}''$ for $15''$ pipes.

Weights of lead and yarn given above are for spigot and socket pipes only.

Metalled Roads.

1. Road metal will consist either of broken stone, kankar, laterite, or vitrified brick. Road metal.

When stone is used, it must be hard, tough, and durable no boulders weighing less than 4 seers must be used.

Sandstone shall not be used, unless thoroughly indurated by the action of heat.

Kankar, laterite, or vitrified brick shall be as tough and heavy as can be procured in the locality. A dark blue fracture will generally indicate a good specimen of kankar. Kankar should be obtained from a clay soil in preference to that from sandy.

2. Before soling a road, it must be properly graded with a level or theodolite to remove minor undulations. Soling is given for all roads carrying heavy traffic, except where the formation consists of really dense material. It should not be laid on embankments till they are thoroughly consolidated. New roads, soling.

The road surface will first be barrelled as in paragraph 6, watered and well rammed. Usually the soling will be 6″ wider on each side than the proposed width of metal. Soling should usually be laid 6″ thick, and will consist of large stones, laterite, kankar or overburnt brick-bats carefully hand packed, with the interstices filled in with smaller pieces of the material used.

3. The metal must be square, sharp, and free from pebbles or long splinters. The specification as to size will vary according to the nature of metal and weight or roller available, from $1\frac{1}{2}''$ to $2''$. The size specified is the diameter of a ring through which each piece should pass in any direction. For laterite the specification may be for a 4″ ring. Stone or brick road metal should be passed over a $\frac{1}{2}$ screen *in situ*, the screenings being collected in heaps between the stacks and the edge of the road. When it is impracticable to screen out the small stuff, a good deal can be done by raking out the piles of stacked metal before loading into baskets for spreading. The effect is to let much of the fine stuff fall through to the bottom, where it can be left till required for top dressing. Preparation and collection of metal.

4. The screened metal will be stacked in long continuous heaps along one side only of the road, and clear of the roadways, openings for drainage being left as required. The stacks will usually be 13″ high, which will be counted as 12″ only for the purpose of

measurement and payment, and of such a section as to give sufficient metal for the corresponding length of road. At cross roads a sufficient length of double stacks will be given and care must be taken that the stacks do not encroach on either roadway.

The metal will be measured for payment in the stacks.

Spreading the metal.

5. Earthen bunds, puddled on the inner side, and of the height of the metalling, will be made along the edge of the soling, so as to give the exact width of the metal, and to prevent its spreading.

Camber.

6. The camber to be given may vary from $\frac{1}{24}$ for narrow roads in very wet climates to $\frac{1}{60}$ for wide roads in dry climates. For most plains stations a slope of $\frac{1}{40}$ is about right for 16′ to 20′ roads of good metal. The camber should not exceed the minimum found suitable for local conditions.

Templates of the full width of the surface to be metalled are required and must be freely used in shaping the surface prior to soling spreading the metal and checking the surface during consolidation.

Consolidation.

7. Rolling should be commenced from the edges, and carried on towards the centre of the road.

The metal will first be rolled dry twice, after which it must be freely flooded with water during consolidation.

Not more than 6″ of metal will be consolidated at one operation.

The metal will be rolled until it is quite hard and compact, so that a light cart passing over it makes no impression on the surface.

Rolling.

8. The first principle of macadamizing is thoroughly to consolidate clean, square, evenly graded stone metal. No binding or surfacing material must be used till the consolidation of the metal is complete. The number of times each section must be traversed by the roller, depends on the weight of roller used, the size and hardness of the metal, the amount of watering and the skill of the engine driver, but it is the worst kind of economy to cut the rolling fine.

9. After thorough consolidation, the screenings, supplemented as necessary by gravel or sand, will be spread evenly, watered and rolled. The object is to fill the interstices between the metal and produce an even water resisting surface. The surfacing should not be thicker than ½″ before rolling and may often be less. Ordinary earth must not be used for this purpose if avoidable.

10. After a length of new metalling has been finished it is essential to keep it well watered and to attend at once to any patches which show signs of working loose. Constant attention for some weeks is necessary to get the best results.

11. The junction of old and new metalling must be made with a long ramp or slope, which must not be terminated with a feather edge, but buried in the old metal.

12. When kanker, laterite, or brick metal is used it should be rammed in the first instance with iron rammers, or rolled with only a light roller until partially consolidated. Care must be taken that the roller used in all cases is not so heavy as to crush the metal.

13. These will be dressed off at a slope of 1 in 40 for a width of from 6 to 12 feet. Berms.

14. The preparation, collection, spreading and consolidation of the metal will be as described for new roads. Remetalling, old roads.

15. The surface of the old road will be cleaned, well roughened with pickaxes, all ruts and hollows filled with broken metal, and thoroughly soaked with water before the new metal is laid.

16. The contractor shall use all due precaution for the safety of passengers by placing an efficient barrier across each end of the length of road which is being worked upon. General.

Bright lights will be kept alight on each barrier all night, and a chowkidar will be maintained to give due warning to persons using the road.

17. No traffic will be permitted to pass over a road when under repairs, which means that proper barriers must be provided. If necessary to meet the convenience of the public, only one-half of the width of a road will be repaired at a time.

18. It is most important that all ruts and holes in a road should be repaired as soon as they appear. The worn place should be cut out to the full depth of the metal of a rectangular form, enclosing the patch, with sides parallel to the centre line of the road, the edges being kept vertical. Patch Repairs.

19. Road metal, as specified above, is then to be laid in the holes its surface being half its depth above the road. It is then to be consolidated with water and heavy iron rammers after which a top dressing of fine stuff is put on and rammed in, until the finished surface of the new patch lies perfectly even with the surface of the road.

20. When a curve has to be given to join up two roads the following is an easy method of laying out the curve. Curves.

Produce the lines of the two roads till they meet. From the point where they meet, mark off a number of equal lengths along each line, as shown in fig. 1, and join the points 1—1, 2—2 3—3, etc. The points of intersection will be the position of points on the curve.

21. In order to keep a record, in compact form, of all metalling operations, a book should be kept in the following manner. Road records.

Each road should be shown diagrammatically on a separate page of the book, all cross roads or conspicuous objects being entered, and miles and furlongs marked on the plan. The opposite page should be divided up into squares, and marked horizontally with the number of the mile or furlong, and vertically with the year. See figs. 2 and 3.

As metal is collected and consolidated, the corresponding squares will be hachured as shown.

Unmetalled Roads and Bridle Paths.

General.

22. All repairs should be carried out on common sense principles, so that the causes of the damage as well as the effects are removed, to prevent any possiblity of recurrence of the damage

In many cases, a short re-alignment will be found the most satisfactory method of executing repairs, so as to bring the road on to harder or more suitable ground.

23. The main objective in road repairs is to keep the water off the road. This is effecited by means of—

(*i*) catch-water drains;
(*ii*) side drains; and
(*iii*) cross drains under and over the road.

The construction of a road along a hill side alters the whole system of natural drainage. Drainage works will at first be confined to what is obviously necessary until after the experience of one rainy season.

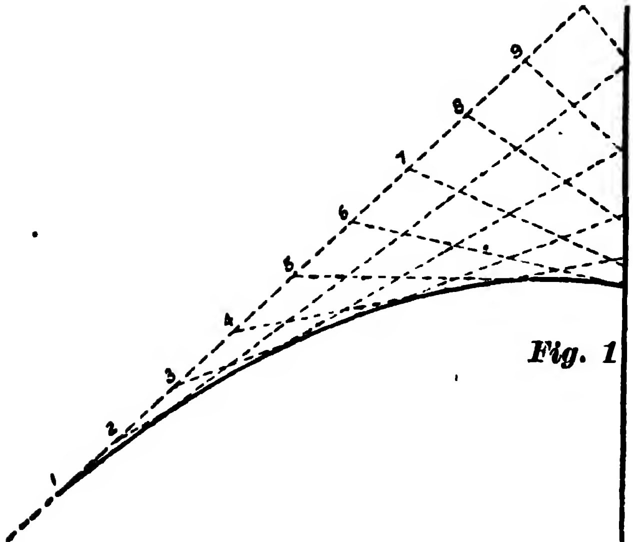
Catch-water drains.

24. Catch-water drains are intended to divert water coming from the ground above the road, so as to make it pass across the road at the cross drains. They are worse than useless on treacherous hill-sides.

On slightly sloping ground the herringbone pattern of drainage is the best, care being taken that the drains running across the slope overlap or join those running up and down. The ends of these catch-water drains should meet about 30 feet away from the road, if possible.

On undulating ground a continuous drain over the high ground between the low places should be made about 30 or 40 feet away from the road. The natural slope of the ground will give the fall necessary to bring the water on to the cross drain.

On steep ground it is usually advisable to give continuous catch-water drains, as in undulating ground, but to place them close to the road, generally about 10 or 15 feet away.


1
2
3
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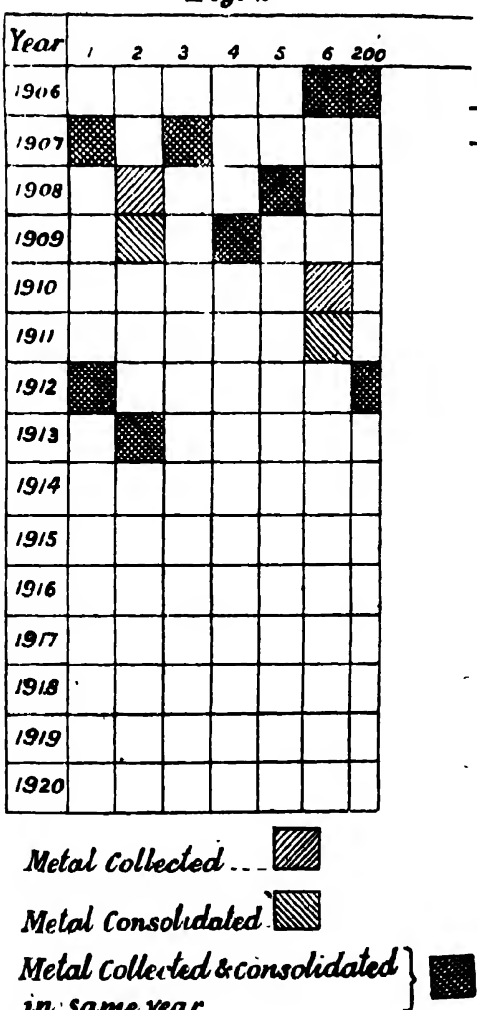
9

Fig. 1

Fig. 2


Year
1
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200
1906
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1911
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1914
1915
1916
1917
1918
1919
1920
Metal Collected
Metal Consolidated
Metal Collected & consolidated in same year

Arrangements for getting the water away after it has crossed the road must be specially looked to. Catch-water (drains-contd.).

On roads where embankments have been made, if there are bridges, continuous drains leading the water under the bridges are required. If there are fillings and no bridges, a continuous drain as in fig. 4, sloping slightly both ways and taken across the road where the cutting and filling meet, should be given.

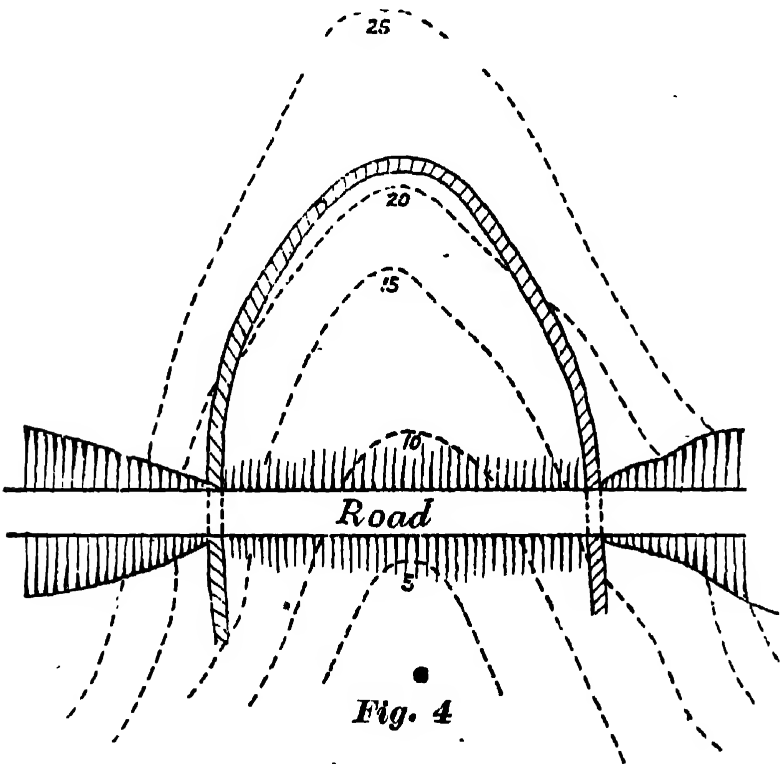


Fig. 4

25. Side drains take the water, which falls between the catch water drains and the road. If they are liable to scour, they should be paved, if possible, or scour prevented by providing at intervals small stone walls, whose top surfaces should be at the level of the bottom of the drain. Side drains.

In order to allow traffic to use the whole width of the road, the bottom of the side drain should be a continuation of the slope of the barrel of the road.

26. Water may be carried under a road by :— Cross drains.

(*i*) Permanent bridges and culverts.

(*ii*) Dry stone culverts.

(*iii*) Corrugated iron or reinforced concrete pipe culverts.

(*iv*) Percolating causeways of large boulders assembled with ample intervals.

Water may be carried over a road by—

Paved causeways or Irish bridges.

Cross drains —(*contd.*).

27. Wherever possible, cross drains should cross the road at right angles. Irish bridges on the skew cause great discomfort to travellers and damage to vehicles.

28. A catch-pool should be provided at the head of every cross drain of importance for arresting boulders and debris washed down from above The bottom of the catch-pool should be a foot or more below the floor or sill of the cross drain.

29. Rain-water must be given a clear flow both above and below the cross drain in the direction in which it is desired to make it go. Clearing is therefore generally necessary above the road and diverging bunds of boulders will often serve to lead the flow into the cross drain.

30. Drainage on steep hill roads with zigzag turns requires much care, to direct the drainage of the upper portions to the cross drains of the road below.

Bridges and culverts.

31. For permanent bridges, arches should be used wherever possible. They are more permanent than girders or galvanized iron sheets, and require less looking after.

32. Skew arches are easiest built with their courses parallel to the abutments, as the end stones only have to be cut to special shape.

33. Culverts up to 4 feet span can be economically built of dry stone, the cover being made of stone slabs, or reinforced concrete or the sides corbelled out and then slabbed over. 12 inches, at least, of earth or metal should be placed over the slabs.

34. Reinforced concrete or corrugated iron cylinders can often be used as culverts. Each end must be completely protected by masonry so that water does not form a false channel along the outer skin of the pipe. In the latter case, if concrete is rammed round the cylinder, a permanent culvert is formed.

35. The floors of culverts must be sloped. This slope should be that of the hillside, but should never be less than 1 in 12.

36. A good curtain wall should be given at the lower end, and large stones rolled in front to break the impact of the water.

37. No culvert should be less than two feet span, so that a boy can get up it to clean it out.

38. In general, it is better to provide a culvert too large than too small.

Irish bridges.

39. Where big boulders, logs of wood, etc., are likely to block a culvert, or bridges cannot be given from want of funds, Irish bridges must be made.

40. An Irish bridge should be laid out with three curves—as in the sketch Fig. 5, to avoid bad bumps. The sketch shows an Irish bridge constructed on a slope.

Fig 5

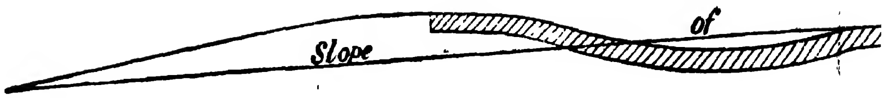
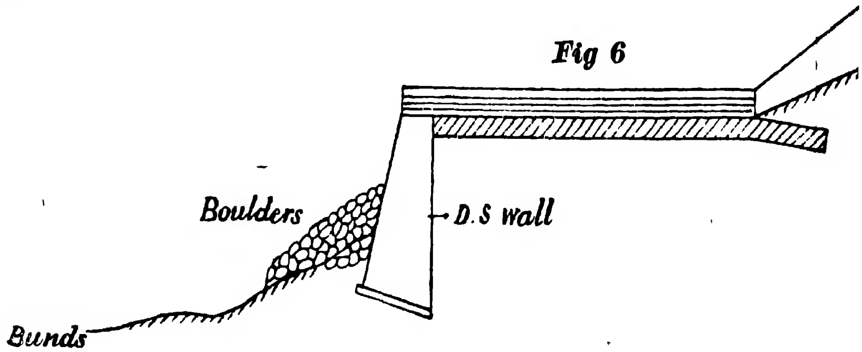


Fig 6



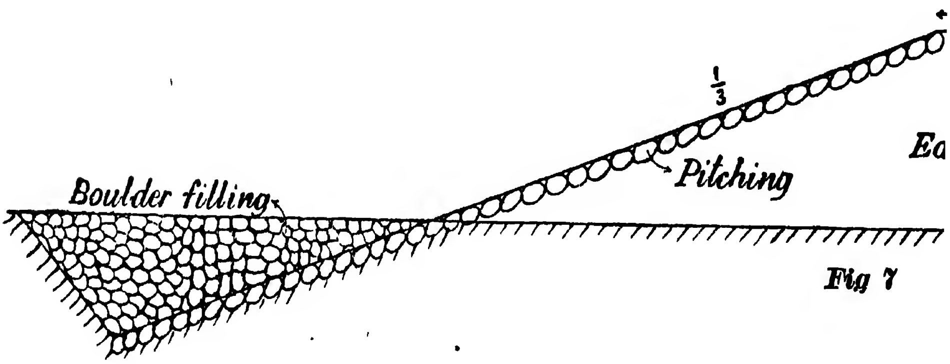


Fig 7

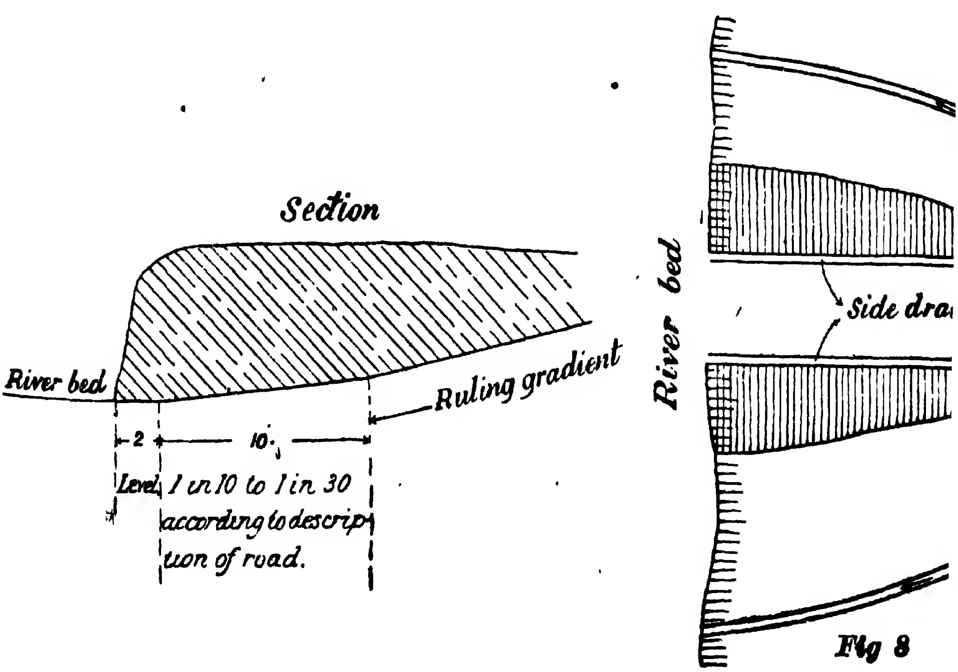


Fig 8

Fig. 6 shows a section across the road of an Irish bridge with a considerable fall below. Irish bridges—(*contd.*).

41. A suitable section for a guiding bund is shown below. Fig. 7. Bunds.

If it is thought that floods may overtop this class of bund, it must be pitched on the top and at the back, the back being sloped at 1 in 3 and the toe excavated, similarly to the front.

This description of bund should be set at an angle of not more than 45° with the direction of the flood, or it would probably be washed away.

The bank end must be well housed into the bank of the stream, and protected as far as possible to prevent any chance of flowing water getting at this end.

The stream end of the bund must be pitched on both sides, and as a flood after passing a bund makes a small whirl-pool down-stream of and behind the bund, some pitching or filling of large boulders must be given at and behind the end of the bund.

42. Ramps into river beds are often badly cut up through want of drainage. Ramps.

The drainage should be arranged as shown in the drawing, which also gives a suitable section of a ramp. Fig. 8.

A small bund placed on the upstream side of, and close to the ramp is frequently of use to prevent the river bank from being cut away.

43. In side cutting, all debris should be thrown down hill. In through cutting, a berm at least 2 feet wide should be left between the edge of the cutting and the thrown up earth, etc. Clearing and surfacing.

All big stones and boulders should be removed, by blasting if necessary, to a depth of 6 inches below the road surface. The surface is finally brought to the desired shape, by means of templates used with masons' levels to ensure their being placed level across the road.

44. Where necessary, the road must be protected by short lengths of parapet walling or large blocks of stone with suitable gaps for drainage. If walling is used, it must be strong, say 2 feet thick and 3 feet high. If blocks of stone are used, each stone should be of such a size that one man cannot move it. Guard walls.

45. Miles stones should be provided, and furlong posts as well on roads for wheeled traffic. These stones should be fixed as accurately as possible and if the width of land taken up for the road is not too great, they can be used as boundary pillars to demarcate the land. Mile stones.

The letters and numbers should be large and clearly marked in black on a white ground.

Gradients.

46. (*i*) For wheeled traffic. Maximum gradient 1 in 20, with not less than 300 feet of practically level length in each mile—the rise per mile not to exceed 240 feet.

(*ii*) Camel road. Ruling gradient to be 1 in 10, with a maximum gradient of 1 in 8 for short lengths of not more than 400 feet provided that a similar and adjacent length in each case is 1 in 12, and that the total rise in any mile does not exceed 500 feet.

(*iii*) Mule road. Ruling gradient to be 1 in 7, with a maximum of 1 in 5 for lengths of 200 feet or 1 in 6 for lengths of 300 feet, provided that immediately adjoining the steep portion, a reduced gradient of 1 in 9 and 1 in 8 is made for a corresponding length and that the total rise in any one mile does not exceed 750 feet.

Curves

47. On roads for wheeled traffic, curves should not be less than 60 feet radius, except at re-entering angles. In all curves sharper than 100 feet radius, the rise in 100 feet should be one-twentieth of the radius.

On camel roads the curves are not to be less than 10 feet radius at the centre of the road, and all curves less than 20 feet radius are to be level for a length of 20 feet.

For mule roads the curves at the bends in zigzags are not to be less than 6 feet radius at the centre of the road, and for a length of 10 feet are to be level.

Notes on Steam Road Rollers.

Types of rollers.

1. Motor rollers are only useful for light work: for road work the steam road roller is unequalled. Rollers capable of being converted into traction engines have not proved a success as a rule.

For roads metalled with kankar or soft, easily crushed, metal, or for district roads, where soling is often absent or lightly provided, a light 6-ton roller is suitable.

For hard metal 8, 10, 12 or even 14-ton rollers should be used.

It should be remembered that the nominal weight of a roller is based on its weight empty and that when the boiler, etc., are full, the actual weight is 10 to 15 per cent. greater.

Compound rollers cost Rs. 450 to Rs. 600 more than single cylinder rollers, but are about 30 per cent. more economical in fuel and water consumption when actually at work, easier to handle, make less noise and last longer. Unless fuel and water are exceptionally cheap and repairs difficult to carry out properly, compound rollers should be used in preference to single cylinder rollers.

Erection.

2. If possible the firm supplying the roller should be called upon to erect it. When, as is usual, this course is impracticable a man with some experience in this form of work should be employed,

the man should be supervised carefully and the instructions furnished by the makers followed in every respect. A spare part catalogue will be found useful in this connection. Erection—(*contd.*)

3. Two men, a driver and steersman, are required for every roller. The driver should be a man qualified to take charge of a steam boiler with experience of road rollers: in the absence of the latter qualification some .tution by an experienced man should be given him. The pay of a driver varies from Rs.30 to 60 per mensem. Labour for working.

Any intelligent coolie will do for a steersman: he is often termed the fireman, but it is the duty of the driver to attend to the fire, when the roller is at work. A dirty roller is the sign of a careless slovenly driver.

If coal is used, a good quality Indian coal is suitable. If wood fuel is used, the fire box and firebars should be especially adapted for the purpose and the point should be brought to notice when the roller is ordered. Generally good dry wood can be burnt without a special firebox, etc., but not wood of inferior calorific value. In a working day of 10 hours, 7 maunds of good coal will be required for a 10-ton compound roller and double or treble this quantity of wood. A single cylinder roller will use 20 per cent. more. If the fire is banked up every night, economy in coal and lighting up wood will result. To bank up, damp down the fire with small coal and half burnt ashes, close the damper and place a cover over the top of the chimney. Drivers avoid banking up as it means trouble after the day's work is over: instead they often arrive late in the morning and force up steam quickly with a large amount of wood fuel, which is bad for the boiler and results in leaky tubes. An excessive consumption of lighting up wood is a certain indication of this practice. When working a thin even fire should be maintained. Fuel.

5. The cleanest water obtainable should be used: any water from a muddy roadside pond will not do. Saline water is to be avoided and its use can be readily detected by slight incrustation appearing at the glands, cocks or joints. Both muddy and saline water cause "priming", *i.e.*, water getting mixed with the steam: priming damages the valves and cylinders: it is at once indicated by violent agitation of the water in the gauge glass and may be checked by keeping the water level in the boiler as low as possible. Saline water may injure the boiler seriously and, if its use is unavoidable, expert advice should be obtained. A 10-ton compound roller will require about 300 gallons of water daily and a single cylinder roller about 33 per cent. more. Water.

6. Castor or other vegetable oils are often used for cylinder lubrication: they tend to carbonise at high pressures and to choke Oil.

Oil—(*contd.*). the steam passages and the exhaust with deposit. A high class mineral cylinder oil should always be used.

A vegetable oil will do for bearings but a heavy mineral engine oil is generally cheaper and better. The manufacturer's advice may always be taken regarding the nature of oil to be used.

In cold or wet climates grease is used for the gearing, but in a dusty country a heavy engine oil, as recomended for the bearings, is to be preferred as the grease merely collects and retains the dust, forming an abrasive compound, which will cause excesive wear in the gearing.

Boiler. 7. This is the most important part of a road roller and the Garrison Engineer should see that it is treated with proper care. Every week or fortnight, depending on the amount of work and purity of the water used, half a day should be set aside for cleaning the boiler, packing the glands, etc., refilling and raising steam. The boiler must only be cleaned when quite cold. The plugs or mud hole doors below the firebox must all be removed and all mud, etc., thoroughly worked out from all four sides by means of a small force pump if possible. If the mud is allowed to accumulate above the level of the firebars, the firebox plates may become overheated, when they will bulge or crack and the stays may leak or even get broken, involving expensive repairs. The manhole door in the boiler barrel should be removed once a year at least, more frequently if the water is bad, and as much clearing and scaling done as possible. If incrustation of the tubes and other surfaces is very marked, expert advice should be obtained. The fusible plug which is provided in the firebox crown plate should be removed at least once a year, oftener with saline water, and carefully cleaned. An encrusted fusible plug may not melt when the boiler is short of water and the result may then be an explosion. Spare fusible plugs are usually supplied and if there is any doubt about the one in use, it should be changed. The boiler tubes should be kept clean inside by sweeping one or more times daily with a tube brush : if this is not done, they may get encrusted with scale requiring the use of special tube cleaners. If the tubes leak at their junction with the tube plates, as a result of bad feed water or from working for long periods on steep gradients and not seeing that sufficient water is used to keep the ends of the tubes covered, they should be expanded with a tube expander, but repeated use of this tool is inadvisable. Leaky tubes always indicate improper working. Before lighting up, the water in the gauge glass should stand half way up : this height must be maintained by a uniform feed.

Steam pressure. 8. Raising steam will take 1 to $1\frac{1}{2}$ hours, depending on the fuel and whether the boiler is cold : the process should not be

hurried by using a blower, which is a cock that sends a jet of steam up the funnel to increase the draught: the blower is only intended to lighten a dull fire, when the engine has been kept standing. If steam is raised too quickly the boiler may be strained through unequal expansion. Steam pressure—(*contd.*)

Compound rollers usually work at a pressure of 180lbs. and single cylinder engines at 140lbs. The boiler should be worked continously at full pressure: many drivers think that economy results in working at low pressure, but this is not the case. There is no excuse for frequent blowing off from the safety valves. The pressure gauge should be tested periodically.

A roller should not be reversed without shutting off steam, as the practice causes wear and tear and if done when travelling at high speed, a breakage may result.

9. In the rim of the hindwheels there will usually be found a number of holes plugged with wood. When the roller is required to travel over slippery ground or on steep slopes, these plugs should be removed and the holes fitted with the frost spikes supplied with the roller. Frost spikes.

10. The following stores will be required for a 10-ton compound roller, working 10 hours a day:— Consumption of stores.

(*a*) Good coal, 7 maunds a day: or, if wood fuel is used, 14 to 21 maunds.

(*b*) Wood fuel for lighting, 1 to 2 maunds a week.

(*c*) Cylinder oil, $\frac{1}{4}$ gallon a day.

(*d*) Heavy engine oil, $\frac{1}{3}$ gallon a day.

(*e*) Cotton waste, $\frac{1}{3}$lb. a day.

(*f*) Kerosine oil, for cleaning only, 1 bottle a week.

(*g*) White and red lead, 2 to 3 lbs. of white and 1 to $1\frac{1}{2}$ of red annually for joint making.

(*h*) Fine copper wire and worsted, 2 or 3lbs, of each annually for oil cup syphons.

(*i*) Jointing materials, one sheet asbestos millboard $4' \times 4' \times \frac{1}{16}''$ annually for mudhole and manhole joints, etc. Mudhole joints can be obtained specially prepared or may be made up of asbestos twine: the former give less trouble. If used only once the number required represents the number of times the boiler is washed out, multiplied by the number of mud holes: but if joints are carefully opened and if a little black lead and tallow is smeared over one surface, the joints can be used 3 or 4 times. Specially prepared joints should always be used for the manhole and will usually only serve once.

Consumption of stores—(*contd.*).

(*j*) Packing for glands, about 1lb. of assorted sizes per mensem.

Output of work.

11. A fair day's work under ordinary conditions for a 10-ton roller is the effective consolidation of from 1,000 to 1,500 superficial yards.

Dimensions of rollers.

12. The following dimensions of a 10-ton roller may be found useful in designing bridges, etc. :—

(*a*) Diameter of front wheel 3′ 9½″. Each hind wheel 5′ 3″.
(*b*) Width of front wheel 4′ 0″ Each hind wheel 1′ 2″.
(*c*) Load on front wheel 4 tons. Each hind wheel 3 tons.
(*d*) Distance between hind wheels, centre to centre, 5′ 4″.
(*e*) Distance between front and hind axles. 9′ 8″.

DRAINAGE.

General.

1. In Indian Cantonments a system of underground sewers is rarely practicable on account of the flatness of the ground, the scattered arrangement of the buildings, the difficulties of disposing of the sewage, etc., all of which entail a very heavy initial cost. Urine and nightsoil are disposed of by trenching or incineration, leaving only sullage and stormwater to be considered.

2. In lines of troops small quantities of sullage water can often be disposed of in absorption pits, provided that the soil is of a suitable nature. In bazaars and in lines, etc., situated on clayey soil a system of sullage water drains is essential.

3. Ordinarily the roadside drains, natural nallahs, etc., can be relied on to carry away all stormwater and in most cases the sloping off of the ground surrounding a building to auxiliary earth drains will be quite sufficient. Cases, however, may occur when, on account of the nature of the soil or in crowded localities, such as bazaars, the storm water drainage will need careful consideration and masonry channels may be found necessary.

4. When the necessity for the drainage of any particular locality arises, the cantonment as a whole should be considered and any small scheme, found to be especially urgent, should be arranged so that it can be linked up with the scheme for draining the whole cantonment. It should be remembered that the introduction of a piped water-supply into a station will sooner or later lead to steps being found necessary for the removal of the water after it has been used.

Absorption pits for sullage water

5. Where the soil is highly absorptive, the oxidising properties of the upper layers may be taken advantage of and the sullage discharged into shallow pits, 2 to 3 feet deep. If, however, immediate absorption does not take place, decomposition will occur, and the pit will become offensive: disinfectants must then be used and the depth of the pit may be increased.

Absorption pits for sullage water—(contd.).

6. The pit should be filled with hard broken stone, 1½ to 3-inch gauge, the larger pieces being placed at the bottom : the top is finished off with a layer of rammed gravel. All grease and solids must be removed in a trap : for this purpose a kerosine oil tin placed in the centre of the pit may be used, the tin being well perforated towards the bottom and filled with sawdust covered with grass. Pits must be kept well away from buildings, wells and water. pipes.

Capacity of drains.

7. For sullage water it may be assumed that the whole of the water-supply will find its way to the drains, which must be large enough to carry away the whole quantity in 8 hours. For bazaars it is usual to make an allowance of 2 gallons per head per hour.

8. The capacity of stormwater drains will depend on the nature of the soil, the slope, the maximum rate of rainfall and the proportion of the area occupied by buildings. When the rainfall is heavy and frequently exceeds 1″ per hour, drains should usually be designed to carry away a run off of ½″an hour : in dry localities, where heavy falls are rare, a run-off of ¼″ an hour may be assumed for main drains and as low as $\frac{1}{10}$″ for side drains. A run off of ½″ is equivalent to a flow of ½ cusec from an acre or ·0116 cusecs per 1,000 square feet.

The practice in regard to the run-off allowance to be made varies a great deal :—

(*a*) In Bombay 1″ an hour is allowed : 70 per cent. of this being taken for suburban areas and 15 per cent. for rural districts.

(*b*) Silk gives for towns in Bengal West of Burdwan ¼″ per hour in urban and ⅙″ in rural districts : double these allowances for towns East of Burdwan.

(*c*) The United Provinces Government rules give ¼″ per hour, unless the rainfall is very heavy when ¼″ to be allowed : for main drains ¼″ per hour.

9. It will often be necessary to use the same drain for carrying off sullage and stormwater and its size will depend on the latter consideration.

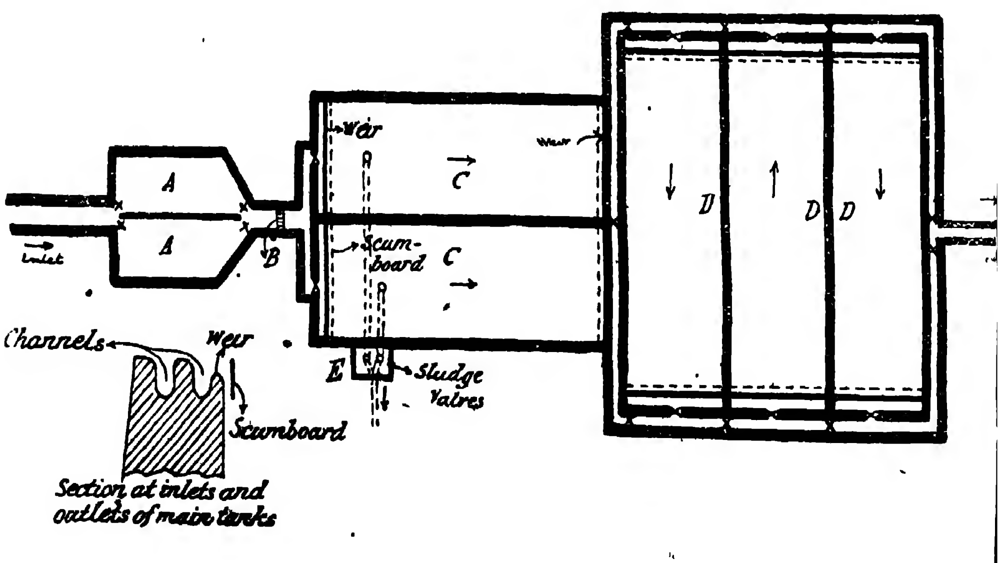
Arrangement of drains.

10. The first requirement is a large scale plan of the area, fully contoured and showing all buildings, roads, existing drains, etc. The drainage system should follow the natural drainage of the country as far as possible. The area will then be divided into sections, the water from each being collected in branch drains

Arrangement of drains—(contd.). leading to the main outfall drain. The alignment of the main drain must be settled first, having regard to the outfall.

Outfall. 11. The outfall is a matter of primary importance and will require careful consideration. It must be remembered that sullage water from a bazaar is nothing less than a form of sewage: if it is allowed to trickle along a large nallah, evil smelling pools will result. A perennially flowing stream is to be preferred, in which the sullage water is at once well diluted. If only a dry nallah is available it may be necessary to pass the sullage water through a settling tank before passing it to the nallah. A method that has several advantages, is to use the sullage water for irrigation on fields, but such operations should be under efficient supervision and carried on well away from cantonments: clay soil will be found unsuitable unless large areas can be made available.

Septic tanks. 12. The best form of settling tank is perhaps the septic tank, which is merely a settling tank in which the sludge is allowed to remain and partially to decompose into liquids and gases. An arrangement which has proved successful is illustrated here:



The sullage water first enters one of the grit tanks, A, A, which are small tanks, capacity ½ hour flow, depth about 3½ feet, where sand, clay, etc., settle. Grit tanks are provided in duplicate, one in use, one thrown out for cleaning: cleaning can be done by hand, the sludge extracted being trenched. B is a screen to arrest floating matter: it is made of inclined ½" bars about ½" apart. C, C are primary tanks and D, D, D secondary tanks. Ordinarily the sewage is let into both the primary tanks and then led through the

secondary tanks in series. Most of the sludge will settle in the primary tanks and sludge valves should be provided at the bottom near the entrance, the bottom of the tank being sloped to this point. The sludge pipes should lead to a valve chamber E, whence the pipes are led away to trenches. The sludge outlet level should be 3 feet below the water level to allow sufficient head to force the sludge through. Tanks D, D, D, may be made flat bottomed : sludge will accumulate in them very slowly and clearing out can be done by hand. The sewage enters and leaves each of the tanks over a level crested weir, beyond which is placed a sludge board, dipping about 9 inches into the water. The total capacity of the primary and secondary tanks should amount to about 12 hours flow : their length should be 3 times their breadth and their depth 6 feet : they should be covered with loose boards or some covering that permits of free ventilation, but prevents mosquito breeding. Stormwater should be excluded and it may be necessary to provide some form of storm overflow or method of diverting the drainage to a nallah. Grit tanks will probably require clearing daily : for the septic tanks, the sludge should be measured periodically and the depth should not exceed 1 foot : the sludge valves of the primary tanks should be opened once a month until the water level in the tanks has dropped 1 foot. Scum should not be allowed to get more than 3 inches thick. Penstocks, *i.e.*, boards sliding in grooves, are provided where marked X and enable any tank to be cut out. **Septic tanks —(contd.).**

13. If storm water only has to be dealt with, the cheapest possible form of drain should be adopted, which will withstand the erosion. Where sullage water is to be carried, the drain should be narrow and deep in order to obtain the maximum velocity of flow. For small flows semi-circular drains may be used, but where the drain has to be calculated for a large stormwater flow the pegtop section is suitable. The flow of water in such drains can be calculated by means of the tables attached. **Design of drains.**

14. For a drain to be self-cleansing, the velocity should be not less than 3 feet a second : in the plains, the grades will be too flat to permit of this velocity being attained and flushing will have to be resorted to. The following velocities should not be exceeded : $2\frac{1}{2}$ f. s. for sandy soil to 4 f. s. for firm soil. $7\frac{1}{2}$ f. s. for masonry to 15 f. s. for rock. At culverts the grade should be doubled. Large unlined drains should not have a steeper slope than $\frac{1}{1200}$, otherwise scouring will occur. If a steep gradient is unavoidable, drop walls and water cushions should be provided at intervals : the water cushions must be drained.

Design of drains—(*contd.*).

15. In plate 45 several forms of drains are shown. The invert may be of stoneware pipes, specially manufactured by Messrs. Burn & Co., at Raneegunge and Jabalpur or cement concrete moulded in 3 feet lengths or lime concrete cement plastered. The sides of the drain may be of stone or brick, cement pointed or of lime concrete, cement plastered.

16. Moulded lime (hydraulic) concrete invert blocks are largely used in the United Provinces. They are made in well oiled moulds in the reverse position to that which they occupy on the work: the lime concrete is rammed in layers and the final tamping is continued until the top becomes soft and pulpy. The concrete is left for 3 days to set, being kept damp the whole time: the sides of the moulds can be removed after 24 hours. When finally removed from the mould, the blocks are placed in a tank for 24 hours and the invert is then cement plastered with plaster of 1 cement and 1 sand well rubbed in and polished. When the plaster has set the blocks are placed in a tank for 7 days. Blocks are made 2 to 3 feet long.

Laying drains.

17. The trench is excavated and levelled as specified for cast iron pipes. The concrete, etc., is laid and finished as described in the detailed specifications for these classes of work. Stoneware pipes should always be laid on a bed of lime concrete: they are jointed with cement mortar composed of 1 cement to 1 sand. Bends, tees, etc., can be obtained from the makers of the pipes, or they may be made of 1.2.4 cement concrete *in situ*.

Flushing.

18. For small side drains a bhisti and a sweeper can clean up 3,000 running feet morning and evening. For larger drains special flushing arrangements are necessary: an efficient method is to place vertical boards in grooves at intervals of 150 to 200 feet and to let the water pond up, when it will proceed with a rush on the board being removed. For main drains a flush of 250 gallons twice a day will be necessary.

Culverts.

19. The bed slope of a culvert should usually be about 1 in 30. The wing walls are splayed at 45° and the embankment sides lopes may be taken as 1 in 1½. The bed should be made pakka and a paved apron given downstream to distribute the flow and to prevent undercutting. For large culverts, where considerable flows at high velocities may occur, a low bund, 50 feet down stream, will usually prevent any scouring round the foundations of the bridge.

20. To ascertain the probable maximum flow of water through the culvert, the catchment area of the nallah should be roughly estimated and the following run off per hour allowed :— Culverts (*contd.*).

$3\frac{3}{4}$ inches per hour for catchments up to 10 acres.					
$3\frac{1}{2}$	,,	,,	,,	,,	of 100 acres.
3	,,	,,	,,	,,	of 1 sq. mile.
$1\frac{1}{3}$	,,	,,	,,	,,	of 20 sq. miles.
$\frac{3}{4}$	,,	,,	,,	,,	of 100 sq. miles.
$\frac{1}{2}$	,,	,,	,,	,,	of 500 sq. miles.
$\frac{1}{3}$	,,	,,	,,	,,	of 1,000 sq. miles.

For localities where the catchment is everywhere steep and rocky, 50 per cent. should be added to the above figures. A run off of 1 inch per hour from 1 acre is equivalent to a flow of 1 cusec.

21. The culvert must be large enough to carry the flow without any heading up at the entrance. To provide for this culverts should be assumed as only flowing half full, when the approach nallah is wide and shallow : if the banks are steep and the nallah narrow, $\frac{3}{4}$ full may be taken. For arched culverts the top of the culvert for calculation purposes should be assumed as lying half way between the springing and the crown.

22. Having ascertained the height available for the culvert, the depth H of water flowing and the flow Q in cusecs, select a breadth B, then :—

Wetted perimeter, $P=2H+B$

Area, $A=BH$

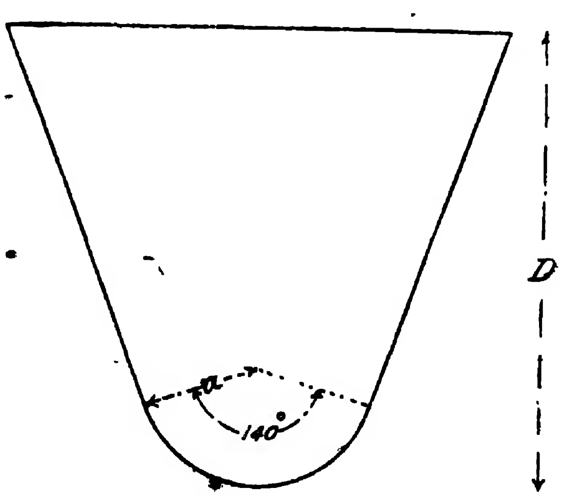
Hydraulic mean depth, $R=\frac{A}{P}$

On the chart align R, with S, the slope, $\frac{1}{30}=\frac{33\frac{1}{3}}{1000}$ and read the velocity V : as N, the constant in Kutters formula, $=\cdot 017$, multiply V by $\frac{3}{4}$: align V thus modified with A and read Q the flow.

Values in feet of R, hydraulic radius, and A, area, of Pegtop and semi-circular drains.

Proportion of D, depth on invert to, a, radius of base.		Radius, a, of segmental portion. 1½"	2"	2½"	3"	3½"	4"	4½"	5"	6"
$D=a$	$R=\cdot5a=$	·0625	·0833	·104	·125	·146	·167	·188	·208	·25
	$A=1\cdot585a^2=$	·0248	·0442	·069	·099	·135	·176	·223	·276	·297
$D=2a$	$R=\cdot771a=$	·0963	·129	·161	·193	·225	·257	·289	·322	·386
	$A=4\cdot077a^2=$	·0638	·1135	·177	·255	·347	·453	·572	·71	1·02
$D=3a$	$R=\cdot982a=$	·123	·163	·204	·246	·286	·327	·368	·408	·491
	$A=7\cdot297a^2=$	·114	·202	·316	·455	·62	·81	1·03	1·37	1·825
$D=4a$	$R=1\cdot177a=$	·147	·196	·245	·293	·342	·392	·44	·49	·588
	$A=11\cdot245a^2=$	·176	·313	·488	·702	·96	·135	1·58	1·95	2·82

For semi-circular drains take as above with $D=a$



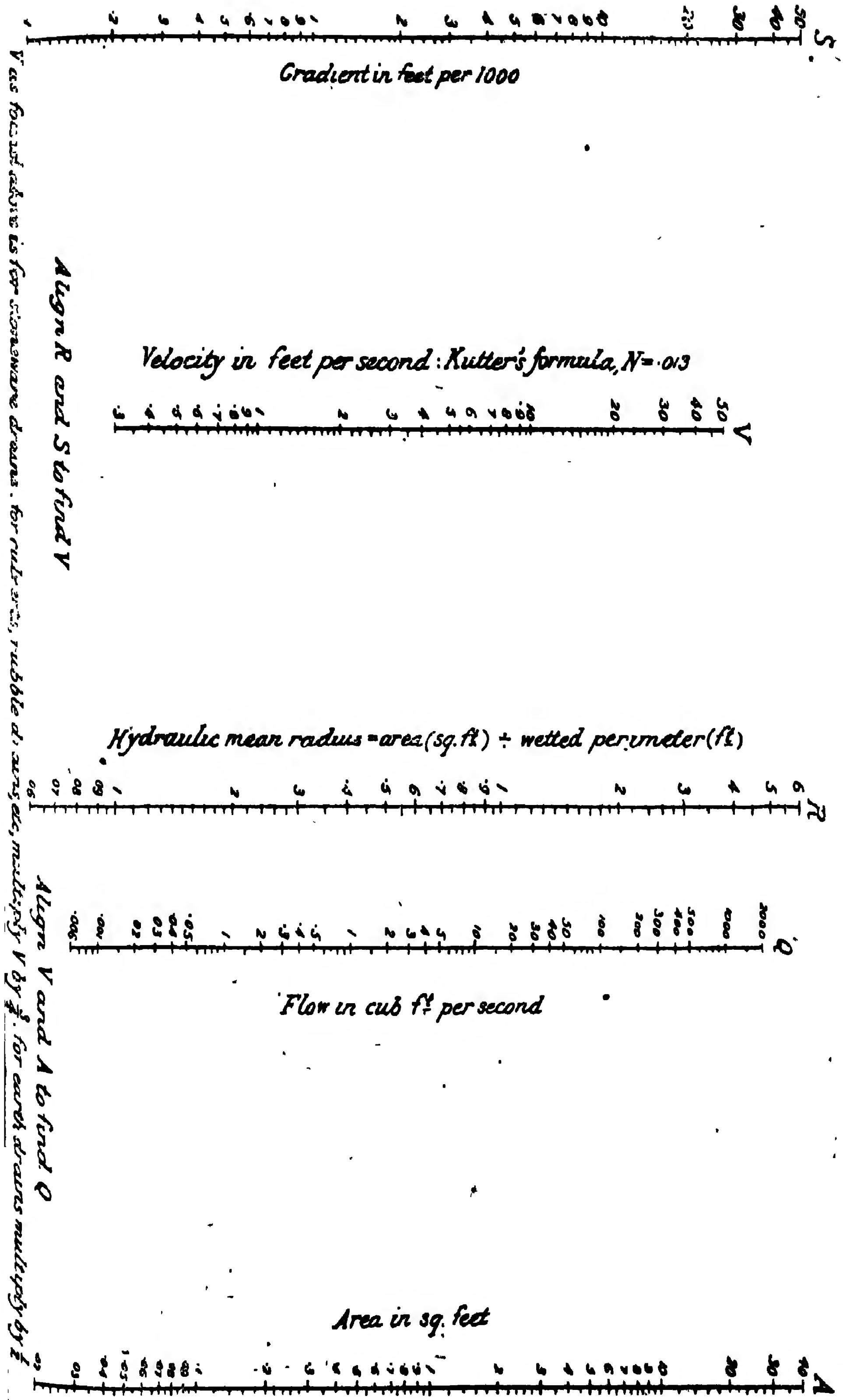
A = area

$= 1{\cdot}585\,a^2 + 2{\cdot}128\,a\,(D-a) + {\cdot}364\,(D-a)^2$

P = wetted perimeter

$= 3{\cdot}17\,a + 2{\cdot}128\,(D-a)$

R = hydraulic radius $= \frac{A}{P}$



S
Gradient in feet per 1000
Velocity in feet per second : Kutter's formula, N = ·013
V
Align R and S to find V
Hydraulic mean radius = area (sq. ft) ÷ wetted perimeter (ft)
R
Q
Flow in cub ft per second
Align V and A to find Q
Area in sq. feet
A

SECTION VI.

Contracts and Rates.

1. Assistant Commanding Royal Engineers are advised to carry out all works in their districts by contract with respectable natives: not only are works executed, as a rule, more cheaply in this manner than by daily labour, but the supervising establishment is thereby saved a large amount of extra work. Contracts.

2. Tenders for all works proposed for execution by contract should be invited in the most public manner possible. This is usually done in practice by posting notices on the prescribed form outside the Assistant Commanding Royal Engineer's office, on public notice boards, and by sending copies to the local Civil officers. The date and hour for the reception of Contractors' tenders should be stated, as well as the date on which the work is to be commenced and finished.

3. While the notices are out, the estimate and plans for the work should be open for the inspection of all persons proposing to submit tenders, and every assistance should be given to enable them to understand thoroughly the details of the work, for the execution of which they propose to tender.

4. All persons, who submit a tender, should fill in the prescribed form, and, when they forward the tender, it must be accompanied by the necessary earnest-money.

5. Tenders should, as far as possible, be opened in the presence of all the tenderers and the result at once made known to them.

6. It is difficult to lay down any fixed rule for guidance in accepting tenders. There is little or no doubt that the practice of accepting the lowest tender in all cases induces Contractors to tender at lower rates and consequently cheapens work. On the other hand, many failures of bad Contractors occur under such a system.

7. A plan often adopted with success is to allow only known and reliable Contractors to tender for an important work, but to make it a rule to accept the lowest tender from among those who have been granted permission to send in tenders.

8. As soon as the tender has been accepted, the Contractor should be given notice of the fact in a book kept for the purpose. At the same time he should be directed to forward his security deposit and be informed of the date on which work is to commence. His signature and that of the Sub-Divisional Officer concerned should be recorded in the book against this notice.

Contracts—(*contd.*).

9. Contractors are bound to make use of the articles on the Government stock as far as possible. In all cases a price list of all stock articles which may be issued to the Contractor is to be prepared. This will be attached to and form part of the contract and will be signed by both parties.

Where the contract is at so much above or below schedule rates a similar list must be prepared showing all rates included in the contract. This list must be signed by both parties, as it is an integral and essential part of the contract. The stock prices of materials issued to a contractor will be deducted from his bill, or he will pay the money in cash as may be directed by the Assistant Commanding Royal Engineer.

10. No women are to be employed on any work within the lines of British troops, while those lines are occupied by them.

11. Written authority signed by the Assistant Commanding Royal Engineer or the subordinate in charge of the work must be produced for any deviations from the measurements or specifications of an estimate. If no such authority can be produced, then the Contractor will be held responsible for the deviation. The measurements referred to are those in the drawings: those in the estimates are for purposes of calculations and not for the information of Contractors.

Rates.

12. All rates for work should be based on carefully prepared specifications. These specifications should be numbered, printed and bound up with the Schedule of Rates. Even when the local specification coincides with that given in this Handbook, the full text should be printed in the district specifications; the Handbook specifications are to be used as a guide only and local specifications will be amplified from them. All specifications should state exactly what work and materials are to be included in the rate. It must not be forgotton that the district specifications form an essential part of most contracts, and that it is hardly reasonable to expect a Contractor to possess himself of a copy of the Handbook or some other book of reference.

13. The compilation of detailed rates for work involves much time and labour, but though no rate can be practically more than a mean, owing to the personal factor of the workmen employed, it is important that for each station there should exist accurate and intelligible details of the rates in the schedule. These records are best kept bound in a book to avoid confusion with tentative rates. The rates in the book should be endorsed with the details of the sanctioning letter as all new rates and changes in existing rates require the sanction of the Commanding Royal Engineer. Detailed

rates are not to be used for settling Contractor's objections. The contract is based on certain specifications, rates and prices of stock materials, which form an indispensable part thereof, and the method of arriving at the rates has nothing to do with the contract. Rates—(contd.)

14. Subordinates in charge of works should frequently be ordered to keep notes of the labour and material employed on various classes of work in progress, both for their own information, and as a check on the recorded detail of rates; such information is also very useful in disposing of the complaints of Contractors.

15. Existing rates will usually be affected by—

(a) Changes in the specifications.

(b) Changes in the adjusted stock rates for materials.

(c) Fluctuations in the market rates for materials.

Changes in the specifications almost invariably necessitate getting out a revised rate and should consequently only be made when really necessary.

16. Changes in stock rates for materials need not necessarily involve a change in the schedule rates concerned. But if any change is made when a contract is running, the Contractor must continue to be charged at the stock rate entered in his contract. Any profit or loss due to the change must be borne by the estimate and not by the Contractor.

17. Fluctuations in the market rates for materials may necessitate a revision of rates from time to time, but so long as contracts based on schedule rates can be placed at or within a few points of par, no general revision of rates will be necessary.

18. When, however, rates have to be revised, it is essential to consult the district specifications and the existing stock rates for materials and to make the necessary changes in all of them concurrently.

19. The specification in use should make quite clear what the rate provides for, and the schedule should contain a column in which a reference to the specification is entered against each item: it is a convenience if the item in the schedule is described reasonably fully. For instance under " ceilings " an item in the schedule " 1" rai planking " conveys but little, but if the item reads "1" rai planking, boards 6" broad, fastened with $2\frac{1}{2}$" nails " the matter is clear at once. Free use should similarly be made of the column of remarks when necessary.

Rates—(*contd.*).

20. Again in the submission of detailed rates by Sub-Divisional Officers, an otherwise unintelligible rate may be made clear by giving a few notes or a handsketch, showing how the rate is arrived at.

21. The rates which follow are based on notes taken of work actually carried out, in most instances in the stations to which the rates refer. They would not be correct for other stations, but form a basis for comparison and a guide as to the points which have to be considered in preparing a similar detail.

Task for an experienced artizan per diem.

Brickwork	15	cubic feet.
Flat archwork	8	,,
Circular	7	,,
Honey-comb work	25	,,
Coursed rubble masonry	5 to 10	,,
Random squared coursed rubble	5 to 12	,,
Random coursed rubble	up to 15	,,
Dressed ashlar	1 to 12	,,
Ashlar in arches	1 to 1½	,,
Plastering 1 coat	60	sq. feet.
,, 3 ,,	30	,,
,, 3 ,,	20	,,
Pointing	100	,,
Terraced floors or roofs	50	,,
Brick-on-edge flooring	45	,,
Flagged flooring	20	,,
Allahabad tiling, single	35	,,
,, ,, double	15	,,
Fixing roof battens	100	,,
1 pair batten doors (4′×7′)	8	days.
Teak wood framing, etc.	1	cubic foot.
1 pair panel doors	15	days.
1 ,, ,, Venetian doors (4′×7′)	18	,,

Rates—(contd.).

Load for a two bullock cart.

Bricks ($9'' \times 4\frac{1}{2}'' \times 2\frac{1}{4}''$)	250	
Broken stone	15	cubic feet.
Gravel	15	"
Kankar lime	13	"
Slaked lime	15	"
Sandstone	9	"

1. Stone Lime Burning.

Station—Chakrata.

Details of labour and materials per 100 c. ft quarried stone.	No or quantity.	Rate.		Amount.	Total.
		Cost.	Per		
LABOUR.		Rs.		Rs.	Rs.
Quarrying stone	..	..	..	1·063	..
Royalty	..	..	..	1·00	..
Carting stone 600 yards in wheelbarrows .	..	..	..	·75	..
Breaking stone	..	..	..	3·75	..
Loading kiln with fuel	..	..	..	1·063	..
Unloading	..	..	..	·375	..
Screening and stacking . . .	..	..	..	1·673	9·674
MATERIALS.					
Blasting powder and fuse	..	..	..	·313	..
Fuel (hard wood)	140·5	15·00	% cubic feet.	21·07	..
Charcoal	..	..	..	·25	..
Rope, screens, bags, etc.	..	..	..	·50	..
Repairs to kiln	..	..	..	·032	22·165
					31·839
Cost per % cubic feet slaked lime . .	$= \frac{31{\cdot}839 \times 100}{106{\cdot}4}$			= 29·92	30

NOTES.—The above rate is based on the following data which should be ascertained in each individual case :—

100 cubic feet quarried stone = 91 cubic feet broken stone.
100 cubic feet broken stone = 81·2 cubic feet unslaked lime.
100 cubic feet unslaked lime = 144 cubic feet slaked lime.
∴ 100 cubic feet quarried stone = 78·89 cubic feet unslaked lime.
= 106·4 cubic feet slaked lime.

	lbs.
1 cubic foot unslaked lime weighs	58
1 cubic foot slaked lime weighs	45

To the quantity of unslaked lime as it comes from the kiln the factor $\frac{9}{7}$ is applied, and it is taken on stock as slaked," though it actually remains unslaked. This system of accounting requires care, due to air-slaking taking place.

2. (*a*) Kunkur lime manufacture.
(*b*) Lime mortar.

Station—Bareilly.

Details of labour and materials per 100 c. feet.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
(*a*) MATERIALS.			Rs.		Rs.	Rs.
Kunkur	c. ft.	125	11·25	per cent.	14·062	
Burnt kunkur siftings	„	12	W. O.	V.	0·00	
Coal dust	„	13·7	32	per cent.	4·38	18·442
LABOUR.						
Loading.						
Coolies	Nos.	2	·188	each	·376	
		2	·157	„	·314	
Unloading.						
Coolies	Nos.	2	·157	each	·314	
		2	·188	„	·376	
Grinding.						
Buffaloes, pair	Nos.	6½	·625	each	4·063	
Screening and Stacking.						
Coolies	Nos.	1	·095	each	·095	5·538
						23·980
OUTTURN.						Rs. A. P.
Ground lime	c. ft.	100	..	„	..	23 15 6
(*b*) MATERIALS.						
Kunkur lime	c. ft.	60	23·984	per cent.	14 38	
Sand	„	60	5·00	„	3 00	17·38
LABOUR.						
Grinding.						
Buffaloes, pairs	Nos.	1	·625	each	·625	
Watering and stirring up in mill during grinding.						
Beldars	Nos.	1	·25	each	·25	
Coolies	„	2	·188	„	·375	1·25
						18·63
OUTTURN.						Rs. A. P.
Lime mortar	c. ft.	100	..	..	..	18 10 0

NOTES.—About 9·6 per cent. of siftings is added to the kunkur in the kiln, and 10 per cent. of this total amount is added in the form of coal dust for burning.

2. The percentage of lime obtained from the total loading of kunkur and siftings is 70 per cent. This is as measured loose into a [illegible] feet cube box after screening, but when placed in bins 4′ 6″ deep the lime settles, and measures as much as 15 per cent. less. This is however rectified on issue as it is again measured out in the box.

3. Surkhi manufacture.

Station—Jutogh.

Details of labour and materials per 450 c. ft. pounded surkhi.		No. or quantity.	Rate. Cost.	Per	Amount.	Total.
Making brick pats.			Rs.		Rs.	Rs.
Coolies pugging	Nos.	8	·313	each	2·5	
Bhisties	„	12	·375	„	4 5	
Women making pats	„	20	·22	„	4·375	
Boys carrying	„	12	·188	„	2·25	
Mate	„	4	·5	„	2·00	15·625
Stacking.						
Coolies	Nos.	3	·313	each	·939	
Women	„	4	·22	„	·875	1·814
Loading and firing.						
Coolies	Nos.	25	·313	each	7·82	
Mate	„	1	·5	„	·5	8·32
Unloading and stacking.						
Coolies	Nos.	25	·313	each	7·82	
Mate	„	1	·5	„	·5	8·32
Pounding.						
Coolies	Nos.	48	3·13	each	15·00	15·00
Material.						
Firewood	Md.	65	·625	Md.	40·625	40·625
						89·704
∴ cost % c. ft. pounded surkhi	$= \frac{89 \cdot 704}{4 \cdot 5}$	= 19·9 Say Rs. 20.				

NOTES.—The surkhi is burnt in a kiln similar to a lime kiln. Earth is obtained from a pit 60′ distant from the kiln, and is pugged with the feet in the pit itself. Work must be done in dry weather, the pats when made being laid out to dry for 4 or 5 days.

Loading.—The firewood is packed closely at the bottom to a depth of 1¼ feet. This is succeeded by the following layers :—

mule droppings 6″ (obtainable near site).
brick pats 4′
mule droppings 6″
wood 1′
brick pats 4′ and so on till the kiln is full, finishing off as for a lime kiln.

Firing is started from the bottom, and the kiln burns out without attention.

Unloading takes place both from the top, and also through feed hole at the bottom.

Quantities 675 c. ft. of brick pats give 450 c. ft. of pounded surkhi and require 65 mds. of wood for burning.

Pounding.—The pounding is done by hand, by heavy wooden mallets on a stone platform.

4. Lime concrete.

Station—Bareilly.

Details of labour and materials per 100 c. ft. rammed concrete.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
MATERIALS.			Rs.		Rs.	Rs.
Brickbats	c. ft.	1·25	2·00	per cent.	2·50	
Kunkur lime mortar	"	39·25	18·375	"	7·21	9·71
LABOUR.						
Carting brick bats to site.						
Beldars	Nos.	1/32	·188	each	·006	
Coolies	"	2½	·125	"	·312	
Cart	Trips	125/15	·25	trip	2 083	2·401
Carting and delivering mortar at site.						
Beldars	Nos.	1/32	·188	each	·006	
Coolies	"	½	·125	"	·063	
Cart	Trips	39·25/12	·25	trip	82	·889
Breaking, carrying and stacking ballast and mortar ready for mixing on platform.						
Breaking ballast	c. ft.	119	1·5	per cent.	1·785	
Carrying and stacking, coolies	Nos.	2	·125	each	·25	
Carrying mortar, coolies	"	½	·157	"	·079	2·114
Mixing mortar and ballast.						
Beldars	Nos.	2½	·22	each	·55	·55
Carrying and laying mixed concrete.						
Coolies	Nos.	2½	·157	each	·392	·392
Ramming.						
Beldars	Nos.	4	·188	each	·752	
Masons	"	½	·407	"	·203	·955
Watering.						
Bhistis	Nos.	1	·188	each	·188	·188
						17·199
			10 per cent. on labour			·748
						17·947
						Say Rs. 18 per cent. c. ft.

NOTES.—Specification 1½" ballast 100.
mortar 33.

105 c. ft. brick bats give 100 c.ft. ballast.

119 c. ft. ballast required for 100 c. ft. rammed concrete.

2. This last quantity can be conveniently ascertained as follows. Fill up a 1′ cube box with the ballast used locally. Then tip out on to platform, mix with specified amount of mortar and ram mixture in box in 6" layers. Measure the diminution in bulk after ramming, and deduce quantity required.

3. In this rate water is obtainable at site.

4. If brick bats obtainable at site, as is often the case, rate will be reduced by cost of carriage of brick bats, *viz.*, by Rs. 2-6-6.

5. The labour in the hills for mixing, laying, ramming, and watering is about 2 masons and 12 coolies per cent. c.ft.

5. Brickwork, 2nd class in lime in foundation.

Station—Bareilly.

Details of labour and materials per 733 c. ft.		No. or quantity.	Rate. Cost.	Per	Amount.	Total.
MATERIALS.			Rs.		Rs.	Rs.
Bricks	Nos.	10395	6·125	per cent.	63·6	
Lime mortar	c. ft.	220	18·375	"	40·4	104·00
LABOUR.						
Bricks carting	cart trips.	$\frac{10395}{250}$	·25	trip	10·395	
" loading, stacking, etc. . .	coolies	12	·22	each	2·64	
Mortar, carting	cart trips.	$\frac{220}{12}$	·25	trip	4·58	
" loading and taking out of mill .	coolies	4	·22	each	·88	
Wetting bricks and masonry.						
Bhistis	Nos.	4	·25	each	1·00	
Digging and lining pit for soaking bricks.						
Mason . . . 1@·75=·75 Coolies . . . 2@·157=·313 1 063	Nos.	..	..	..	1·063	
Carrying bricks and mortar.						
Beldars	Nos.	6	·22	each	1·32	
Coolies	"	36	·157	"	5·625	
Skilled labour.						
Mistri	Nos.	2	·875	each	1·75	
Masons	"	22	·5	"	11·00	
Masons	"	6	·25	"	1·5	41·753
						145·753
			10 per cent. labour			4·175
						149·928
		∴ cost per cent. c. ft.=$\frac{149·928}{7·33}$				=20·45 Say 20-8-0
		Water at site.				

NOTES.—Bricks $9'' \times 4\frac{1}{2}'' \times 2\frac{3}{4}''$, 1,350 Nos. are required per cent. c.ft. of brickwork+5 per cent. for breakages.

2. The breakages would be used up in concrete. See Rate IV notes.

3. A skilled mason was found in this case to lay 29 c. ft. of brickwork a day in lime, and 34 c. ft. in mud, in foundations. In superstructure he laid about 25 c. ft. in either mud or lime. The daily task for a mason varies considerably with the skill of the local workman. It may be as low as 15 c. ft. a day.

4. For superstructure, 8 annas extra for scaffolding per cent. c.ft. should be allowed.

6. Archwork, 1st class bricks in lime, clerestory windows.

Station—Bareilly.

Details of labour and materials per 20 c. ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
			Rs.		Rs.	Rs.
Bricks, 1st class	Nos.	275	7	per cent.	1·925	
5 per cent. breakages	„	..	..	..	·095	
Lime mortar	c. ft.	6	18·375	per cent.	1·102	3·123
Labour.						
Carting bricks	Trips	110/100	·25	trip	·275	
Lime mortar	„	6/12	·25	„	·125	
Coolies, loading and stacking, etc.	Nos.	1	·22	each	·22	
Wetting bricks and masonry, bhisties	„	1/2	·25	„	·125	
Carrying bricks and mortar, coolies	„	3	·157	„	·471	
Skilled labour.						
Making and opening up centering, masons	Nos.	1/2	·5	each	·25	
Cutting bricks, masons	„	2·75	·5	„	1·375	
Laying bricks, masons	„	2	·5	„	1·00	3·841
						6·964
10 per cent. labour	..	..	..	..	..	·384
						7·348
∴ rate per cent. c. ft. = 7·348 × 5 = 36·74	..	..	..	..	..	Say Rs. 36·120

Notes.—One mason summered 100 bricks a day
2. One mason laid 10 c. ft. per day.
3. Bricks per cent. c. ft. = 1,375.

7. Stone masonry, coursed rubble.

(a) Quarrying.

Station—Sabathu.

Details of labour and material.		Nos. or quantity.	Rate.		Amount.	Total.
			Cost.	Per		
LABOUR.			Rs.		Rs.	Rs.
Quarrymen	Nos.	98	·5	each	49·00	
"	"	98	·438	"	42 875	
"	"	72½	·313	"	22·7	
Coolies for carrying tools for repairs, etc.	"	45	·157	"	7·06	
Coolies with quarrymen	"	26	·25	"	6 5	
Blacksmiths to repair tools	"	22½	·595	"	13 4	141·535
MATERIALS.						
Blasting powder	lbs.	9	·657	lbs.	5 92	
Fuze	r. ft.	5	·021	r. ft.	·105	
Charcoal	Mds.	2	1 5	Md.	3 00	9·025
						150·56
OUTTURN.						
Ordinary stones	Nos.	2,905	2 00	per cent.	58·10	
Bonds and quoins	r. ft.	1,654	·047	r. ft.	77·50	
Arch stones	Nos.	132	·063	each	8·25	
Stone window and door lintels	c. ft.	9	1 00	c. ft.	9 00	152·58

NOTES.—Ordinary stones vary in size from 5″ × 6″ × 7″ to 6″ × 6″ × 8″.
Bonds and quoins are 1½′ long.
2 Cost of quarrying depends on :—
(a) Hardness of rock.
(b) Proportion of good to bad stone obtainable.
(c) Extent to which quarry is choked with debris.
(d) The necessity for blasting ; when assured the stones can be got out by crowbars, sledge hammers and steel wedges.
3. This rate is for a seam of hard dark blue stone associated with considerable quantities of useless rocks. The quarry contained a large amount of debris.
4. According to the prices given to the outturn, one quarryman gets 29 ordinary stones
or 8 bounds or quoins
or 9 arch stones.

(b) Carriage.

Station—Sabuthu.

Details of carriage per 100 stones.		No. or quantity.	Rate.		Amount.	Total.
			Cost.	Per		
			Rs.		Rs.	Rs.
11¼ furlongs by bullock cart	Nos.	100	1·25	per cent.	1·25	
3 furlongs by coolie downhill	"	100	·688	"	·688	1·938
						= Rs. 1-15-0.

NOTES.—Bonds and quoins = 2 ordinary stones.
2. The cart makes 3 trips per diem, carrying 75 stones per trip.
3. The rate per diem per 100 stones = 3 pies by cart
or 7 pies by coolie downhill.
4. Reckoning an average of 340 ordinary stones and 72 bonds and quoins per % c. ft. of masonry, the cost of carriage per % c. ft. of masonry by coolie is Re. 0-3-0 downhill per chain
0-6-0 to 0-8-0 uphill according to steepness.

7. Stone masonry, coursed rubble—(*contd.*).

(*c*) Dressing Stones.

Station—Sabathu.

Detail of labour and materials for dressing stones.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
LABOUR.			Rs.		Rs.	Rs.
Masons	Nos.	19	·688	each	13·063	
"	"	20	·625	"	12·5	
"	"	2	·5	"	1·00	
"	"	68	·438	"	29·75	
"	"	62	·375	"	23·25	
"	"	27	·313	"	8·438	
"	"	68	·25	"	17·00	
"	"	1	·22	"	·22	
Coolies carrying tools	"	27	·157	"	4·23	
Blacksmiths	"	13	·5	"	6·5	115·952
MATERIALS.						
Charcoal	Mds.	6	1·5	Md.	9·00	9·00
						124·951
OUTTURN.						
6" building stones	Nos.	5988	·938	per cent.	69·532	
5" " "	"	1429				
Bond stones	R. ft.	442	2·5	"	11·05	
Quoins	"	900	5·00	"	45·00	125·582

NOTES.—The rate for masonry can be varied almost indefinitely by the amount of dressing demanded.

2. If the chisel is ordinarily used locally, and hammer dressing is all that the rate allows, piece work will be necessary.

3. This rate allows for the minimum of dressing permissible in coursed rubble: the faces of the stones except the quoins, not allowed to have a chisel mark on them, and the beds and joints just shaped down. It works out to Rs. 7-4 per cent. cubic feet of walling, and may rise as high as Rs. 60 per cent. cubic feet if fine dressing is demanded.

4. According to the cost in rate above, one mason will dress per diam 50 to 51 ordinary stones
or 19 to 20 bond stones
or 9 to 10 quoins.

5. If stones are bushed, and dressed to 4" from the face along sides to give ½" joints, a mason will do 4 only per diem.

If stones are dressed as above but with face chisel dressed instead of bushed, a mason will do 3 only per diem.

6. A mason will chisel to shape, and fairly face 8 arch stones a day.

7. Stone masonry, coursed rubble in lime, 18" thick—(*concld.*).

(*d*) Complete rate.

Station—Sabathu.

Detail of labour and materials per 100 c. ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
Stones at quarry.			Rs.		Rs.	Rs.
Ordinary	Nos.	340	2·00	per cent.	6·80	
Bonds and quoins	r. ft.	72×1½	·047	R. ft.	5·063	11·863
Carriage.						
14½ furlongs by cart and coolie, ordinary	Nos.	340	..	..	..	
Bonds and quoins 2×72	"	144	1·938	per cent.	9·37	9·37
		484				
Dressing.						
Ordinary stones	Nos.	340	·938	"	3·188	
Bonds	r. ft.	36×1½	2·5	"	1·350	
Quoins	"	36×1½	5·00	"	2·700	7·238
Laying. Rs. A. P.						
2 masons at Rs. 0-9-0 . =1 2 0						
1 coolie carrying stones at Rs. 0-4-0. =0 4 0						
1 coolie serving, etc., mortar at Rs. 0-4-0. =0 4 0						
½ coolie for water at Rs. 0-2-0. =0 1 0						
Total . . 1 11 0	c. ft.	100	1·688	32 c.ft.	5·28	5·28
Lime mortar.						
Ready mixed	c. ft.	28	43·75	per cent.	12·25	12·25
Scaffolding.						
Share of carriage	..	..	..	..	·125	
Erection coolie	Nos.	1	·25	each	·25	·375
						46·376=46-6-0

Notes.—If the cost of lime mortar be deducted, the corresponding rate for coursed rubble in mud will be found.

2. The number and proportion of stones will vary with the building, and the size that stones are quarried in each locality. This rate is for work on a Departmental Subordinate's quarter, detached.

3. The work being done departmentally, no percentage is added.

4. It will be noticed that the rate is high, due to the long carriage, and to the large number of stones required per cent. cubic feet. In the neighbouring station of Solon, the number of stones per cent. cubic feet of masonry is on an average 270 ordinary stones and 40 bonds or quoins, and it varies with each station:

8. Pointing Brickwork.

Pure Kunkur Lime.

Station—Bareilly.

Detail of labour and material per 1,742 square feet.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
MATERIALS.			Rs.		Rs.	Rs.
Kunkur lime	c. ft.	33·39	23·75	per cent.	7·94	
						7·94
LABOUR.						
Carriage	Cart trips.	33·39 / 12	·25	trip	·694	
Scaffolding, coolies	Nos.	8	·188	each	1·504	
Scraping walls.						
Gharamis	Nos.	9½	·25	..	2·38	
Wetting walls, coolies	"	4	·188	..	·75	
Pointing.						
Masons	Nos.	30	·5	..	15·00	
Grinding mortar, carrying and keeping wet, coolies.	"	11	·188	..	2·068	22·396
						30·336
			10 per cent. on labour			2·239
						32·575
∴ Rate per cent. square feet . .	..	..	..	..	32·575 / 17·42	=1·87= Rs. 1-14 0

Notes.—From this rate a mason does 58 square feet a day and the amount of kunkur lime required per cent. square feet is 1·9 cubic feet.

9. Pointing, on (*a*) Coursed rubble masonry.—(*b*) Flagged flooring.

Station—Kailana.

Unscreened material for mortar.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Screened Materials. Unit.	Screened Materials. Quantity.	Remarks.
Slaked lime . .	c. ft.	1·1	48	Per cent.	·532	c. ft.	1	Water at site.
Bujri . . .	"	9	18	"	1·62	"	2	
Screening and mixing .	..	..	..	..	·11	..	..	
Ropes, bags, screens, etc.	..	..	..	..	·037	..	..	
Total .	c. ft.	10·1	..	..	2·299	c. ft.	3	=2·62 c. ft. mortar.

Detail of labour and material (daily labour).		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
(a) *Coursed rubble masonry* 200 *s. ft.*			Rs.		Rs.	Rs.
MATERIALS.						
Mixed mortar	c. ft.	1⅔	2·299	2·62	1·47	1·47
LABOUR.						
Raking joints, masons	No.	⅜	·75	each	·282	
Pointing . . . { Mason .	"	1·75	·75	"	1·313	
Pointing . . . { Coolie .	"	1·75	·25	"	·44	
Watering coolie	"	3	·25	"	·75	2·785
						4·255
Cost per % s. ft.	..	..	..	..	..	2·127= Rs. 2-2-0.
(b) *Flagged flooring* 193 *s. ft. flags* 2′ × 2′.						
MATERIALS.						
Mixed mortar	c. ft.	⅚	2·299	2·62	·73	·73
LABOUR.						
Raking joints, masons	No.	½	·75	each	·375	
Pointing . . . { Mason .	"	¾	·75	"	·563	
Pointing . . . { Coolie .	"	¾	·25	"	·188	
Watering coolie	"	4	·25	"	1·00	2·126
						2·856
Cost per % s. ft.	..	..	..	..	2·856 / 193	1·48=Rs. 1-8-0

Notes.—The quantity of mortar required per 100 s. ft. of coursed rubble masonry varies considerably with the quality of the masonry. This rate gives ⅚ c. ft. per % s. ft. for an ordinary wall as in Rate VII. A rough and badly built wall may take 8 times as much.

2. From this rate a mason points 114 s. ft. of masonry or 257 s. ft. of flagged flooring a day, raking joints extra

3. Cement or a mixture of cement and lime should be used for pointing floors, the above rates calling attention to the different quantities required for stone masonry and flooring.

10. Lime Plaster on brickwork.

Station—Bareilly.

Detail of labour and materials per 100 s.ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
MATERIALS.			Rs.		Rs.	Rs.
Kunkur lime mortar	c. ft.	4	18·375	per cent.	·735	
Pure kunkur lime	„	½	23·75	..	·119	·854
LABOUR.						
Carriage	trips	4·5 / 12	·25	trip.	·094	
Erecting scaffolding.						
Gharamis	Nos.	½	·25	each	·125	
Raking out joints and wetting walls.						
Beldars	Nos.	1	·188	each	·188	
Bhistis	„	1	·188	„	·188	
Plastering.						
Masons	Nos.	1½	·375	each	553	
Beldars	„	¾	·188	„	·146	1·298
						2·152
				10%	labour	·129
						2·28 say Rs. 2-4-0.

NOTES.—This rate allows for one coat of plaster beaten on with thapies, and for one rendering coat of pure lime

2. On stone masonry, with 1 coat rough, 1 fine, one cream, the masons required for plastering % s. ft. will be about 2½.

3. The quantities required per % s. ft. of stone masonry for materials will depend upon the roughness of the face to be plastered.

11. Cement Plaster 1 : 3 ½" thick with floating coat of ⅛" neat cement on brickwork.

Plains.

Detail of labour and materials per 100 s.ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount	Total.
MATERIALS.			Rs.		Rs.	Rs.
Cement at site 1·56 c. ft. × 91 lbs.	lbs.	142	·048	lbs.	6·82	
Sand at site	c. ft.	4·68	7·35	per cent.	·344	7·164
Floating coat.						
Cement at site 1·32 c.ft. × 91 lbs.	lbs.	120·25	·048	lbs.	5·77	5·77
LABOUR.						
Raking out joints and wetting walls.						
Beldars	Nos.	1	·188	each	·188	
Bhistis	"	1	·188	"	·188	
Plastering.						
Masons	Nos.	1½	·5	each	·75	
Mixing carrying, etc., beldars	"	¾	·188	"	·140	
Keeping wet.						
Bhisti	"	1	·188	each	·188	1·454
						14·388
				10%	labour	·145
						14·533 say Rs. 14-8-0

Notes.—1 c. ft. cement 8 c. ft. sand, course and fine grains mixed, give 264 c. ft. rammed facing mortar. Rammed facing mortar required % s. ft. ½" thick is $\frac{100}{24}$ = 4⅙ c. ft. = 6·25 c. ft. of dry material, *i.e.* 1·56 c.ft. cement and 4·68 c. ft. sand.

2. For floating coat 1 c. ft. of neat Portland cement will cover about 9½ s. ft. 1" thick or 76 s. ft. ⅛" thick The amount required per % s. ft. is therefore $\frac{100}{76}$ = 1·32 c. ft.

3. In the above, 1 c. ft. Portland cement = 91 lbs.

4 Nothing is allowed for scaffolding, as the work is generally done on the bottom of walls, where scaffolding is not required.

12. (*a*) White washing.
(*b*) Colour washing.

Station—Naini Tal.

Details of labour and materials per (*a*) 2148 s.ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
MATERIALS.			Rs.		Rs.	Rs.
White lime	lbs.	53¾	1·063	80	2 7	
Gum	chittaks	10	·063	chittak	·625	
Brushes, etc.	..	..	..	..	·063	1·408
LABOUR.						
Masons	No.	1½	·5	each	·75	
Coolies	„	2	·25	„	·5	1 25
						2 658
				10%	labour	·125
						2·783
Cost per % s ft. one coat on new work.	..	..	..	..	2·783 / 21·48	=·13 say 0-2-0
(*b*) 2086 *s. ft.*						
Whitelime	lbs.	54	1 063	80	·72	
Sulphate of copper	seers	5	·75	seer	3·75	
Gum	chittaks	10	0·63	chittak	·63	
Lemons, brushes, chattics, cloth, etc.	..	..	..	..	·438	5·538
Labour.						
Masons	Nos.	2	·5	each	1·00	
Coolies	„	2¼	·25	„	·563	1·563
					..	7,101
				10%	labour	·156
						7·257
Cost per % s.ft. one coat on new work	..	..	..	..	7·257 / 20·86	= ·348 = Rs. 0-5-6.

NOTES.—Specifications differ widely locally, according to the quality of the lime, local custom, etc.

2. In rate (*a*) 53¾ lbs. of lime was mixed with 29 gallons of water, 28½ gallons of wash resulting. Area covered per gallon 76 s. ft.

In rate (*b*) the ingredients were mixed with 33 gallons of water, which gave 31 gallons of colour wash. Area covered per gallon 69 s. ft.

3. For all coats the specification remains the same, and the above rates are for the first coat on *new work*. For the first coat on *old wash*, including sweeping down walls and removing loose scale, add 6 pies to above rates; for 2nd and subsequent coats on old or new work deduct 6 pies from above rates, to allow for bandobast of ghurras, ladders, etc., already made.

4. For colour wash, the quantity of colouring matter to be added will of course vary with the depth of colour required.

13. 1″ P. C. Concrete Flooring.

Station—Chakrata.

Details of labour and materials per 8060 s. ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
MATERIALS.			Rs.		Rs.	Rs.
Bujri, coarse	c. ft.	672	18	per cent.	121·00	
Bujri, fine	„	269	18	„	48 4	
Portland cement	lbs.	12903	·058	lb.	748 375	
Share of watering cans, carting, cement, etc.	..	..	..	..	20 00	917·775
LABOUR.						
Masons	Nos.	46½	.75	each	34·875	
Masons	„	26½	·625	„	16·563	
Masons	„	6½	·595	„	3·867	
Coolies	„	81	·375	„	30·375	
Beldars, watering	„	20	·25	„	5 00	
Mate	„	23	·5	„	11 5	102·180
						1019·955
Cost per % s. ft.	..	..	..	..	$\frac{1019·96}{80·6}$	=12·65= Rs. 12-10-6.

NOTES.—Specification 1 : 2 : 5. Portland cement taken as 1 c. ft. = 96 lbs.

2. The above rate is for work done by daily labour with most careful organisation, timing and supervision. The floor was laid out in 2½′ strips, and each mason was given a square 2½′ × 2½′ to consolidate and polish. Exactly half an hour was allowed from the moment cement was wetted to the finish of the polishing, *viz.* :—

Mixing and spreading 5 minutes.
Ramming 10 minutes.
Polishing 15 minutes.

For each mason one coolie was employed in washing and screening bujri, measuring quantities accurately, mixing concrete and carrying to site.

3. This gives 1 mason and 1 coolie per 100 s. ft. of floor excluding watering, and this amount of labour is about the minimum possible by careful arrangements. In most cases it will be more than double, say 2 masons and 6 coolies.

4. The rate also allows for no wood for battens, thapies, etc., which would have to be added if no old wood were available.

5. As regards ballast, if this has to be broken from hard blue stone, a coolie will not break more than 1 c.ft. a day to the requisite size. Overburnt refuse from kunkur lime kilns is sometimes procurable, and an experiment, carried out at Bareilly on such ballast, gave the following quantities per 100 cubic feet of rammed concrete (*vide* note 2, Rate IV).

Cement 18·5 c.ft., sand 37 c.ft., ballast 93 c.ft.

The ballast contained about 40% voids, and a good deal of fine stuff.

In each case to arrive at a rate, it is necessary to carry out a similar experiment with the ballast and sand as usually used locally.

6. The Portland cement should always be dealt with by weight.

7. About 4½ gallons of water should be mixed with material for 100 square feet of flooring.

14. Wooden Flooring.
(*a*) Butt jointed fixed with nails.
(*b*) Rebated, fixed with screws, boards 6″ broad.

Station—Naini Tal.

Details of labour and materials per 100 s. ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
(*a*) MATERIALS.			Rs.		Rs.	Rs
1¼″ chir planking delivered at site	s. ft.	110	·12	s. ft.	13·2	
3″ nails, 200 × 1·75 lbs. per % nails	lbs.	3·5	11·25	cwt.	·35	13·55
LABOUR.						
Carpenters—						
(*i*) Planing surface and trueing edges	Nos.	1½	·625	each	·94	
(*ii*) Fixing	"	1	·75	"	·75	
Coolies	"	2	·25	"	·5	2·19
						15·74
					10% labour	·22
						15·96 = Rs. 16
(*b*) MATERIALS.						
1¼″ chir planing delivered at site	s. ft.	120	·12	s. ft.	14·40	
2¼″ screws	Nos.	154	1·00	gross	1·07	15·47
LABOUR.						
Carpenters—						
(*i*) Planing and rebating	Nos.	2	·625	each	1·25	
(*ii*) Fixing	"	1	·75	"	·75	
Coolies	"	2	·25	"	·5	2·50
						17·97
					10% labour	·25
						18·22 = Rs. 18-4-0

NOTES.—Planks 10′ × 6″ × 1¼″.

Rate (*a*). 10% allowed for wastage. Joists assumed 2½′ apart, and two nails per plank per joist gives 10 × 20 = 200 nails per 100 s.ft.

Rate (*b*). Floor surface of 6″ plank is 5½″ only. 10% allowed for wastage. In 100 s ft. there are 22 planks, and allowing 2 screws at either end of each plank and one at each intermediate joists gives 7 × 22 = 154 screws per 100 s.ft.

2. The amount of planing, etc., required will vary considerably. The above rate is for well sawn planking.

15. Renewing Earthen Floors for stables.

Station—Bareilly.

Details of labour and materials per 100 c. ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
			Rs.		Rs.	Rs.
Digging and filling earth into carts .	c. ft.	100	2·5	%.	·25	
Carting	trips	100/20	·25	trip	1·25	
Digging up old floor and loading into carts	c. ft.	100	2·5	%.	·25	
Carting away outside cantonment limits	trips	100/20	·25	trip	1·25	
Watering and ramming, beldars . .	Nos.	4	·188	each	·75	3·75
						Rs. 3-12% c.ft.

16. Woodwork wrought, framed and fixed, as in trusses, chowkats, etc.

Station—Naini Tal.

Details labour and materials per 1 c. ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
			Rs.		Rs.	Rs.
Chir scantlings up to 14′ long .	c. ft.	1	·875	c. ft.	·875	
Wastage 10 %	..	..	..	..	·087	·962
LABOUR.						
Carpenter	Nos.	⅔	·75	each	·50	
Coolie	,,	½	·25	,,	·125	·625
						1·587
					10% labour	·062
						1·649 say Rs. 1-10-0

NOTES.—Measurements to be taken over all, to include joints.

2. The labour required per c. ft. varies with the hardness of the wood. The above rate is for a soft new wood. The labour per c. ft. at Bareilly for making chowkats out of sal wood, sawn from beams which had been in position in a roof for 30 or 40 years, was exclusive of sawing, 1½ carpenters and ½ coolie.

17. Sawing sleepers.

Station—Chakrata.

Details of labour per 100 s ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.
			Rs.		Rs.
Deodar sleepers 10′ × 10″ × 5″.					
Two sleepers cut into planks 1½″ and 1″ thick.					
Area of cuts 58⅓ s.ft. done by 2 carpenters at annas 8 each in 7 hours 20 mins. ∴ area cut in 8 hours at Re.1 $= \frac{58 \cdot 33}{7 \cdot 33} \times 8 = 63 \cdot 7$ s ft. cost per 100 s.ft. ofcuts.	s.ft.	100	1·00	63·7 s. ft.	1·57 = Re.1-9-0.
Rail sleepers 11′ × 10″ × 5″.					
Five sleepers sawn into planks. Two sawn into scantlings. Area of cuts 216⅓ s.ft. done by 2 carpenters at annas 8 each in 22 hours 50 minutes ∴ area cut in 8 hours at Re. $1 = \frac{216 \cdot 33}{22 \cdot 833} \times 8 = 75 \cdot 6$ s.ft. cost per 100 s.ft. of cuts.	s. ft.	100	1·00	75·6 s. ft.	1·32 = Re. 1-5-0.

Notes.—The rate depends on the hardness of the wood. At Bareilly it was found that a pair of sawyers (at annas 12 each) would do the following for new sal logs 75 s.ft. of cuts a day or Rs. 2 per cent. s.ft of cuts. Ditto small scantlings along and across 60 s.ft. or Rs. 2-8 per cent. old seasoned sal 50 s.ft. or Rs. 3 per cent. s.ft.

2. In the last case, the sawyers, forming a sort of trades union, refused to do more than 50 s.ft. a day.

3. An experiment with carpenters at annas 6 each gave a rate of Rs. 2-8 per cent. s.ft. of cuts from old seasoned sal.

4. Old seasoned wood should take 25 per cent. more labour for sawing than new wood.

18. Lime plaster ceiling on ¾" wire netting.

Station—Bangalore.

Detail of labour and materials per 875 s.ft. of ceiling.	No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.	Grand Total.
Materials.		Rs. A. P.		Rs. A. P.	Rs.	Rs.
Lime mortar (1 lime to 2 sand).	66 c.fts.	15 0 0	% c.ft.	9 14 0	From actuals.	
Hemp . . .	11 lbs.	0 6 0	lb.	4 2 0		
¾" Mesh I. wire netting	109 s. yards	15 0 0	50 s. yards	32 11 2		
Wire nails . .	8 lbs.	0 2 0	lb.	1 0 0		
50 ft. I wire .	2 lbs.	0 3 0	lbs.	0 6 0		
					Rs. 48-1-7	
Labour.						
Carpenters .	17	0 12 0	each	12 12 0	From actuals.	
Masons . . .	14	0 12 0	"	10 8 0		
Male coolies .	4	0 6 0	"	1 8 0		
Female coolies . .	8	0 3 0	"	1 8 0		
Boy coolies . .	6	0 3 0	"	1 2 0		
				27 6 0		
Profit on labour at 10%	..	..	..	2 11 10	Rs. 30-1-10	
Total cost for 875 s.ft.	..	..	..	..	..	Rs. 78-3-5
Total for 100 s.ft. .	= Rs. 8-15-0	..	..	..		
Whitewashing 2 coats	Re. 0-2-6	..	..	..		
	Rs. 9-1-6	say Rs. 9				
Lime plastered ceiling on ¾" wire mesh including white-washing 2 coats.	..	..	..	..	..	9 Rs. % s.ft.

19. Ceiling.

(a) 1" chir planks 6" broad, rebated, with beading 1"×1½" over joints.
(b) Ditto butt jointed under sheets.

Station—Naini Tal.

Detail of labour and materials per 100 s. ft		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
(a) MATERIALS.			Rs.		Rs.	Rs.
1" chir planking	sq. ft.	120	8·4	per cent.	10·08	
2½" nails Nos. 154×1·2 lbs. per cent.	lbs.	1·85	11·25	cwt.	·019	
Beading.						
8 planks×5 sq. ft.	sq. ft.	40	8·4	per cent.	3·36	
Screws, 1½"	Nos.	110	·5	gross	38	13·84
LABOUR.						
Planing and rebating, carpenters. .	Nos.	2	·625	each	1·25	
Sawing and preparing beading, carpenters	,,	2	·75	,,	1·50	
Fixing the whole—						
Carpenters	,,	3	·75	,,	2·25	
Coolies	,,	3	·25	,,	·75	5·75
						19·59
				10 per cent	labour	·58
						20.17 =Rs. 20-4-0
(b) MATERIALS.						
1" chir planking	sq. ft.	110	8·4	per cent.	9·24	
2½" nails Nos. 154×1·2 lbs. per cent. .	lbs.	1·85	11·25	cwt.	·019	·92
LABOUR.						
Planing and hanging—						
Carpenters	Nos.	1½	·625	each	·94	
Fixing carpenters	,,	2	·75	,,	1·50	
Coolies	,,	2	·25	,,	·50	2·94
						12·20
				10 per cent.	labour	·29
						12·49
						=Rs. 12-6-0

NOTES.—For planks and nails *vide* notes to Rate 14.

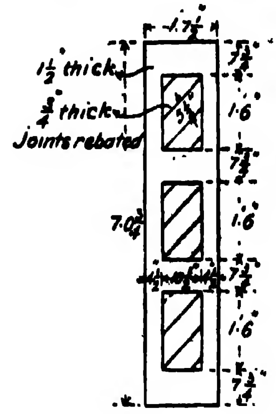
2. For beading, a plank 10'×6"×1" will give 8 pieces 10'×1½"×1'. In a square 10'×10', 22 lengths of 10' are required or ²²⁄₃=7⅓', say 8 planks, to allow for wastage. 5 screws 1½" are allowed per length of 10'.

3. The labour is higher than that allowed in Rate 14, to provide for scaffolding and the more difficult portion of the work.

20. Chir panelled door, 1½" thick, in two leaves.

Station—Naini Tal.

Detail of labour and materials per 22 sq. ft.			No. or quantity.	Rate. Cost.	Rate. Per	Amount	Total.
				Rs.		Rs.	Rs.
MATERIALS.							
1½" chir planking.							
In one leaf—							
2×7·06×·375 . .	=5·29						
4×1·625×$\frac{7·75}{12}$ . .	=4·20						
	9·49						
10 per cent. wastage	·94						
In two leaves . . .	2×10·43	sq. ft.	20·86	·12	sq. ft.	2·51	
¾" chir planking.							
In one leaf—							
3×1½×·88 . . .	=3·96						
8 per cent. for rebates .	=·32						
10 per cent. for wastage .	=·43						
In two leaves . . .	2×4·71	sq. ft	9·42	·076	sq. ft.	·72	3·23
FITTINGS.							
Cleats 2×4"×2"×1" . .		c. ft.	·01	·875	c. ft.	·01	
Hinges for above, 3" . .		Nos.	2	·157	each	·31	
„ for door, 4" . .			6	·22		1·32	
Tower bolts, 9" . . .			2	·56		1·12	
„ 6" . . .			2	·375		·75	
Thumb latch . . .			1	1·00		1·00	4·51
SCREWS.							
1¼" per 3" hinge 6=2×6= per 4" hinge 8=6×8=	60	Nos.		0·55	gross	·24	
1" per bolt 8=4×8= per latch 12=1×12=	44		44	0·35	gross	·11	·35
LABOUR.							
Making and hanging—							
Carpenters . .		Nos.		·75	each	9·00	
Coolie . . .				·25		·25	9·25
							17·34
					10 per cent.*	labour	·92
							18·26
						18 26	
Cost per sq. ft.							=·83=Rs. 0-13-0 s.ft.



NOTES.—Area of whole door allowing 1½" for overlap of leaves is 7' 0¾"×3' 1½"=22 sq. ft.

2. The labour will vary according as the wood is very hard or very soft.

3. The labour for panelled and glazed door will be about the same as for a panelled door.

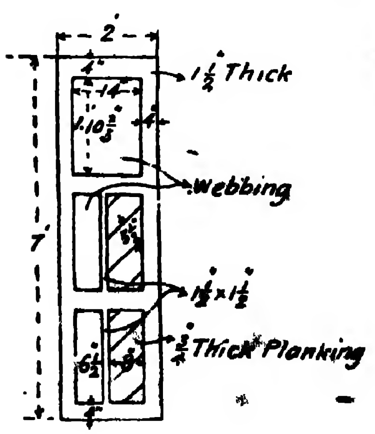
4. A carpenter will do 3½ sq. ft. a day of a chir battened door, and add for hanging ¼ carpenter and ¼ coolie.

5. A door in, one leaf, chir frames 1½"×4", and sheet iron panels, suitable for servants' quarters, will require 4 carpenters and ¾ coolie for making up and hanging.

6. The above rates assume wood is supplied fairly to size required sawing from log extra.

21. 1½″ chir, 64 mesh wire webbing door in two leaves.
Station—Naini Tal.

Detail of labour and materials per 28 sq. ft			No. or quantity.	Rate. Cost.	Rate. Per	Amount	Total.
					Rs.	Rs.	Rs.
MATERIALS.							
1½″ chir planking.							
In one leaf—							
2×7×⅓	=4·67						
4×2×⅓	=2·67						
2×2×⅛	= ·5						
	7·84						
10 per cent. wastage . .	·78						
In two leaves	8·62×2	sq. ft.	17·24	·12	sq. ft.	2·07	
¾″ chir planking.							
In one leaf—							
2×⅔×1·91	=2 55						
8 per cent for rebates .	= ·2						
10 per cent. wastage .	= ·27						
In two leaves	2×3·02	sq. ft.	6·04	·076	sq. ft.	·46	
G. I. wire webbing 64 mesh.							
1½″ all round for fastening.							
Top panel—							
(1·33×2×·1) (1·89+2×·1	sq. ft.						
=1·53×2·09 . . .	=3·19						
Other panels—							
2 (0·54+2×·1) 2·09=2×							
0·74×2·09	=3·07						
	6 26						
10 per cent. wastage . .	·62						
In two leaves	2×6·88	sq. ft.	13·76	·25	sq. ft.	3·44	5·97
FITTINGS.							
Hinges, 4″		Nos.	6	·22	each	1·32	
Handles		,,	2	·407	,,	·81	2·13
SCREWS.							
1″ for fillets at 4 per r. ft. 2×4×16·94 r. ft.		Nos.	136	0 35	gross	0·33	
For handles at 6 each 2×6		,,	12	0·35	,,	0·03	
1½″ per 4″ hinge 8=6×8=48 . . .		,,	48	0·56	,,	0·19	0·55
LABOUR.							
Making and hanging—							
Carpenters		Nos.	9	·75	each	6·75	
Coolies		,,	1	·25	,,	·25	7·00
							15·65
					10 per cent.	labour .	·70
							16·35
Cost per sq. ft.		..	..	..	..	16·35 / 28	=·58 say Rs 0-9-0



NOTES.—The leaves butt, so area is 2×7×2=28 sq. ft.

2. Spring hinges will be paid for separately according to pattern specified.

3. Fillets for fastening wire webbing are not paid for as materials as they will be made from wastage.

4. See note 6, Rate 20.

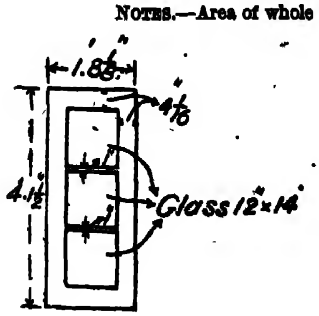
5. Doors should be designed as far as possible so that wastage of wire webbing is a minimum.

22. Window, 1½" chir, glazed, in two leaves.

Station—Naini Tal.

Details of labour and materials per 12·9 sq. ft.			No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
				Rs.		Rs.	Rs.
MATERIALS.							
1½" chir planking.							
In one leaf—							
2 × 1·67 × ·334 . .	=1·12						
2 × 4·125 × ·334 . .	=2·76						
2 × 1·083 × ·083 . .	=0·18						
	4·06						
10 per cent. wastage . .	·41						
In two leaves . . .	2 × 4·47	sq. ft.	8·94	·12	sq. ft.	1·073	1·073
Glasses 12" × 14"		No.	6	·657	each	3·94	3·94
FITTINGS.							
Cleats, 2 × 4" × 2" × 1"		c. ft.	·01	·876	c. ft.	·088	
Hinges: for above, 3"		Nos.	2	·157	each	·314	
Do. window, 4"		"	4	·22	"	·88	
Tower bolts, 6"		"	2	·375	"	·75	
Do. 4"		"	2	·157	"	·314	2·266
SCREWS.							
1" per bolt 8=4×8		Nos.	32	0·35	gross	·078	
1½" per 3" hinge 6=2×6=12 per 4" hinge 8=4×8=32 44		"	44	0·56	"	·172	·25
Putty, brads, etc., for glasses . .		..	..	..	..	·125	·125
LABOUR.							
Making and hanging—							
Carpenters		Nos.	6½	·75	each	4·875	
Coolies		"	1	·25	"	·25	5·125
							12·779
					10 per cent.	labour .	·513
							13·292
Cost per sq. ft.		..	..	..	..	13·292 / 12·9	=1·03 say Rs. 1.

NOTES.—Area of whole window, allowing for overlap, is 4½′ × 3⅛′ = 12·9 sq.ft.
2. See note 6, Rate 20.



23. Ironwork.
Bolts and nuts.

Station—Bareilly.

Details of labour and materials per 92 bolts and nuts, ¾" × 7½" = 26·44 lbs.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
MATERIALS.			Rs.		Rs.	Rs.
Iron	lbs.	28	·078	lb.	2·188	2·188
Coal	cwt.	½	·595	cwt.	·298	
Oil for cutting threads	lbs.	$\frac{1}{12}$	·188	lb.	·016	
Coal tar	"	¼	·173	"	·043	·357
LABOUR.						
Making 92 bolts.						
Blacksmiths	No.	3	·5	each	1·5	
Boys, bellows	"	3	·125	"	·375	
Making 92 nuts.						
Blacksmiths	No.	3	·5	each	1·5	
Boys, bellows	"	3	·125	"	·375	
Cutting threads on bolts and nuts.						
Boldars	No.	3½	·22	each	·77	4·52
						7·065
Cost per cwt.	..	..	..	..	$\frac{7\cdot065 \times 112}{26\cdot44}$	= 29·95 say Rs. 30

NOTES.—All ironwork is best done departmentally. Bolts and nuts should nearly always be purchased from a good firm.

2. In the case of bolts and nuts, a rate per cwt. cannot be arrived at which is even approximately correct for all sizes of bolts and nuts; for whilst the cost of coal, oil and labour remains approximately constant *per bolt and nut* the rate *per cwt.* will vary enormously with the diameter and length of the bolt.

3. This fact is more easily legislated for if work be done departmentally, the estimate allowing for a fixed rate per bolt and nut, irrespective of size, for coal and labour (in this case pies 10), and the material required being calculated from the tables, *plus* 20 to 25 per cent. for wastage on the weight of the finished *nuts*.

24. Ironwork.
Cold work and rivetting.

Station—Bareilly.

Details of labour and materials per 206 lbs.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
MATERIALS.			Rs.		Rs.	Rs.
Uprights— Angle iron—1½" × 1½" × ¼" . . 9 × 7½' × 2·33 lbs. = 157						
Door frames— Angle iron—1" × 1" × ⅛" . . . 4 × 6' × 0·8 lbs . = 19; 4 × 3' × 0·8 lbs . = 10						
186	lbs.	186	·079	lb.	14·69	
¼" plate iron, 8 × ½ × ½ × 10 lbs . .	„	20	·079	„	1·58	
½" round iron, 1½' × ·167 . . .	„	25	·079	„	·02	
Coal tar	„	2	·173	„	·35	16·64
LABOUR.						
Cutting angles to sizes.						
Blacksmith	No.	1	·625	each	·625	
Boy	„	1	·125	„	·125	
Straightening.						
Blacksmith	No.	1	·625	„	·625	
Boy	„	1	·125	„	·125	
Making holes for rivets.						
Blacksmith	No.	2	·625	„	1·25	
Boy	„	2	·125	„	·25	
Rivetting plates, 6" × 6" + ¼".						
Blacksmith	No.	1	·625	„	·625	
Boy	„	1	·125	„	·125	
Making pivots and rivetting.						
Blacksmith	No.	½	·625	„	·313	
Boy	„	½	·125	„	·063	4·126
						20·766
Rate per cwt.	..	..	..	..	$\frac{20·766 \times 112}{206}$	= 11·3 say Rs. 11-6-0

NOTES.—The above rate is for the uprights and door frames of a lavatory partition, all work including rivetting, done cold.
2. There is practically no loss of material in manufacture in this case.
3. The cost of labour and coal tar per cwt. is $4·476 \times \frac{112}{206} = 2·43$ = Rs. 2-7-0.

25. Ironwork.
In trusses.

Station—Bareilly.

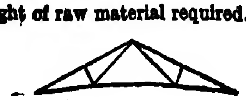
Details of labour and materials per 110 cwt. 3 qrs. 12 lbs.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
MATERIALS.			Rs.		Rs.	Rs.
Mild steel at Calcutta	cwt.	85·66	6·87	cwt.	588·673	
Railway freight	,,	85·66	·977	,,	83·611	
Local carriage	,,	85·66	·046	,,	3·923	
Mild steel from stock	,,	28·054	8·75	,,	245·47	921·677
Coal dust	,,	14·5	·617	,,	8·954	8·954
LABOUR.						
Blacksmiths	Nos.	149	·625	each	93·125	
Do.	,,	139	·5	,,	69·5	
Do.	,,	2	·407	,,	·814	
Do.	,,	20	·375	,,	7·5	
Gharamies	,,	164	·25	,,	41·00	
Hammermen	,,	403	·22	,,	88·157	
Beldars	,,	99	·188	,,	18·563	
Coolies	,,	2	·157	,,	·313	
Do.	,,	327	·125	,,	40·875	
Do.	,,	9	·095	,,	·845	360·692
						1,291·323
Cost per cwt.	..	..	..	..	$\frac{1,291·323}{110·856}$	= 11·63 = Rs. 11-10-0

NOTES.—The above rate is for making up departmentally and fixing 48 trusses, span 20′, 6½′ apart, to carry D. A. T. roof. P. R. S. 3″ × 3″ × ⅜″ T, ties flats 2¼″ × ½″, 2″ × ½″ and 2″ × ½″ struts, angles 2″ × 2″ × ¼″.

2. The rate for fixing is about annas 4 per cwt.

3. 2½ per cent. should be added to weight of manufactured trusses to give weight of raw material required.

4. The cost of labour and coal is $\frac{369·646}{110·856}$ = 3·34, say Rs. 3-6 per cwt.



26. Ironwork.
Forged.

Station—Bareilly.

Details of labour and materials per 56 lbs. {20 holdfasts and bolts.		No. or quantity.	Rate. Cost.	Per	Amount.	Total.
MATERIALS.			Rs.		Rs.	Rs.
Flat iron, 1½″×½″	lbs.	50	·079	lb.	3·95	
Round iron, ½″	,,	8½	·079	,,	·67	4·62
Coal dust	C. ft.	[illegible]	82	%	·23	·23
LABOUR.						
Blacksmiths	Nos.	4	·5	each	2·00	
Boys	,,	4	·125	,,	·5	
Cutting threads on bolts and holdfasts	,,	1	·25	,,	·25	2·75
						7·60
Cost per cwt.	..	..	..	..	$\frac{7{\cdot}60 \times 112}{56}$	= 15·2 =Rs. 15-4-0

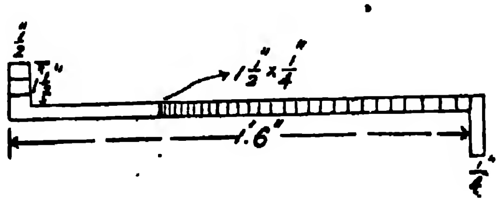
NOTES.—Work done departmentally.

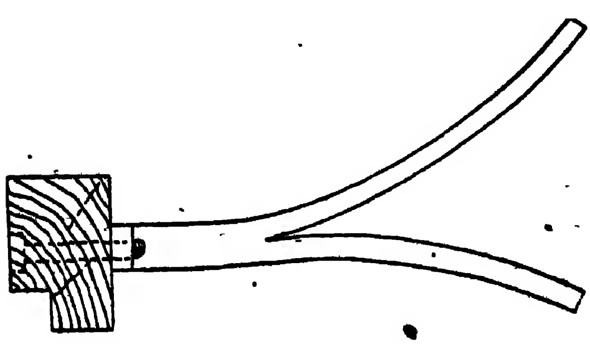
2. The cost of labour and coal is 2·98×2=5·96, say Rs. 6 per cwt.

3. 4½ per cent should be added to weight of manufactured articles to give amount of raw material.

4. An abstract of the cost of labour and coal per cwt., etc., for these four ironwork rates is—

Bolts and nuts	10 pies per bolt and nut.
Iron work, cold	Rs. 2-7 per cwt.
Iron work in trusses	,, 3-6 ,,
Iron work, forged	,, 6 ,,





27. Rolled steel beams.
Fixing only.

Station—Bareilly.

Details of labour and materials per cwt.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
			Rs.		Rs.	Rs.
MATERIALS.						
(*a*) *Replacing wooden beams in an existing roof.*						
Mortar	c.ft.	1	18·375	%	·184	
Kunkur lime	„	⅓	23·75	%	·079	2·63
LABOUR.						
Propping up roof—						
Coolies	Nos.	6×½	·22	each	·66	
Carts	„	1/16	·5	..	·032	
Wedging—carpenter	„	⅙	·5	„	·083	
Fixing—						
Mason	„	½	·438	„	·219	
Beldar	„	½	·25	„	·125	1·119
						1·382 say Rs. 1-6 cwt.
LABOUR.						
(*b*) *Fixing R.S. purlins, weight* 52·47 *cwts.*						
Cutting, where necessary, boring holes and fixing bolts—						
Blacksmiths	Nos.	4	·625	each	2·5	
Do.	„	2	·5	„	1·00	
Carrying, hoisting, etc.—						
Gharamies	„	18	·25	„	4·50	
Beldars	„	27	·22	„	5·907	
Coolies	„	18	·188	„	3·375	
Do.	„	13	·125	„	1·625	18·907
Cost per cwt.	..	..	..	..	18·907 / 52·47	= ·361 = Rs. 0-5-9-

NOTES.—This work is best done departmentally.

2. In (*a*) the roof was a flat terraced verandah roof carried on wooden burghas and wooden beams. The wooden beams were replaced by R. S. beams.

Rate (*b*) is for fixing the purlins on a new tiled roof, carried on steel trusses.

3. In rate (*b*) it should be noted that the beams were of very light section, and experience showed that the cost for fixing beams of ordinary section was annas 4 per cwt.

28. Roofing.
S. A. T. 1st Class.

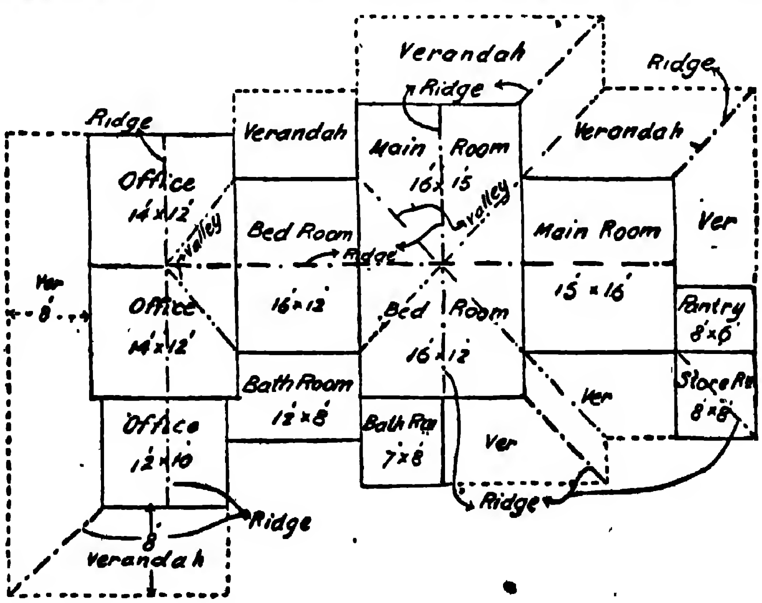
Station—Bareilly.

Details of labour and materials per 1,750 sq.ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
MATERIALS.			Rs.		Rs.	Rs.
1st class flats	Nos.	1,875	28	%	52·6	
,, ½ rounds	,,	1,975	26	,,	51·4	
,, flat 4 button tiles at eaves	,,	150	28	,,	4·2	
3rd class hip tiles	,,	70	20	,,	1·4	109·6
Lime mortar	c.ft.	50	18·375	%	9·188	
Brick ballast at site	,,	60	4·75	,,	2·85	
White lime at site	seers	35	1·595	md.	1·395	13·433
CARRIAGE.						
Tiles	trips	$\frac{4070}{200}$	·25	trip.	5·09	
Lime mortar	,,	$\frac{50}{12}$	·25	,,	1·04	6·13
LABOUR.						
Laying, gharamies	Nos.	31	·313	each	9·703	
Carrying and whitewashing—						
Coolies	Nos.	20	·188	,,	3·75	
Do	,,	20	·156	,,	3·125	
Cutting, masons	,,	2	·5	,,	1·00	
Pointing eaves and hips—						
Masons	,,	2	·5	,,	1·00	
Coolies	,,	8	1·88	,,	1·5	20·078
						149·241
			10% labour and carriage			2·62
						151·861
Cost per 100 sq. ft.	..	..	..	..	151·861 / 17·50	=8·66, say Rs. 8-12-0

NOTE.—This rate is for the roof of the verandah and verandah rooms of building shown in sketch.

2. The disparity between the number of flat tiles and the area covered is accounted for by the ridges and valleys, where the flat tiles have to be cut. The ½ round tiles are also cut where necessary at the eaves.

3. The eaves and hips are filled in for 1 foot with concrete, and the underside of the roof is whitewashed.



29. Roofing D. A. Tiling.

Station—Bareilly.

Details of labour and materials per 1,919 sq. ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
MATERIALS.			Rs.		Rs.	Rs.
Upper layer.						
1st class flats	Nos.	2,024	28	%	56·7	
Do. ½ rounds	,,	2·110	26	,,	54·85	
2nd class, flat, 4 buttons at eaves	,,	86	20	,,	1·72	
Lower layer.						
2nd class flats	,,	2,110	20	,,	42·2	
1st class semi-hexls	,,	2,110	24	,,	50·7	
2nd class semi-hexls, ½ size, next to ridge	,,	220	15	,,	3·3	
1st class flats, 4 buttons, ½ size next to ridge.	,,	220	28	,,	6·16	
1st class ridge elbows	,,	106	50	,,	5·3	
Do. do. ventilators	,,	112	90	,,	10·08	
Filling at valleys and eaves.						
2nd class bricks	Nos.	1,125	6·125	%	6·88	
Lime mortar	c. ft.	47	18·375	%	8·63	
Whitewashing.						
White lime at site	Md.	1	1·595	Md.	1·595	248·115
Carriage.						
Tiles	trips	9098 / 200	·25	trip	11·375	
Bricks	,,	1125 / 250	·25	,,	1·125	
Lime mortar	,,	4	·25	,,	1·00	13·5
LABOUR.						
Laying and carrying—						
Gharamies	Nos.	42	·313	each	13·15	
Coolies	,,	31	·188	,,	5·818	
Do.	,,	30	·156	,,	4·68	
Cutting tiles—masons	,,	14	·5	,,	7·00	
,, gharamies	,,	5	·313	,,	1·565	
Whitewashing—boys	,,	19	·095	,,	1·804	
Laying valleys in mortar—						
Masons	,,	13½	·5	,,	6·75	
Coolies	,,	13	·188	,,	2·438	
Filling in eaves—						
Masons	,,	10	·5	,,	5·00	
Coolies	,,	4	·188	,,	·75	48·95
						310·565
			10% labour and carriage			6·245
						316·810
Cost per 100 s. ft	..	..	..	..	316·81 / 19·19	= 16·5 = Rs. 16-8-0

NOTES.—This rate is for the main portion of the roof shown in previous rate.

2. It is very necessary to specify the class of tile (1st or 2nd) to be used in each part of the roof. The contractor may lose heavily if issued 1st class tiles, when the rate only allows of 2nd class, and will gain in the reverse case.

3. Contractors often claim extra for whitewashing, filling in eaves, etc.; if this is included in the rate, as in this case, it should be specified.

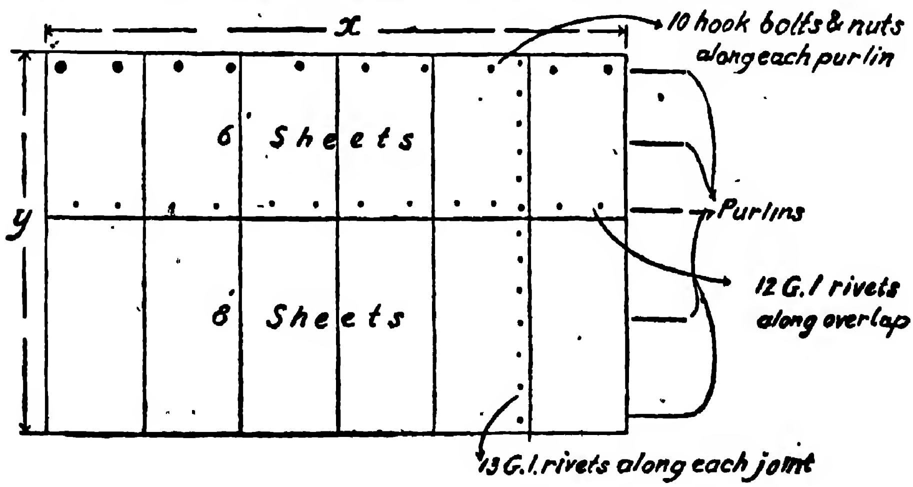
4 The projections at eaves of D. A. T. roofs are generally S. A. T. and paid for as such.

30. Roofing.
C. G. I. 24 G. 32″ Sheets.

Station—Naini Tal.

Details of labour and materials per 182·25 sq. ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total
MATERIALS.			Rs.		Rs.	Rs.
Sheets.						
6 Nos. × 6′ × 32″ = 36 × 3·2 = 115 6 × 8′ × 32″ = 48 × 3·2 = 159	lbs.	274	12·25	cwt.	29·98	
Rivets, G. I., ¼″ × ½″.						
90 No. at 104 to the lb. = $\frac{90}{104}$	lbs.	·865	26·5	,,	·206	
G. I. hooks, bolts and nuts.						
4″ × ½″	Nos.	50	7·5	gross	2·6	
Limpet washers.						
1 per rivet and hook bolt	,,	140	2·00	,,	1·94	34 726
LABOUR.						
Smiths	,,	2	·625	each	1 25	
Carpenters	,,	1½	·75	,,	1·125	
Coolies	,,	3	·25	,,	·75	3·125
						37·851
				10 per cent. labour		0·313
						38·164
Cost per 100 sq. ft.	..	..	..	..	38·164 / 1·823	= 20·9 = Rs. 21

NOTE.—For purposes of comparison rates 30 to 32 are worked out for the same hill station.



1. Area covered—
   X = 6 × 2¾ . . . . . . = 16′ 6″
   Deduct 6 joints, 2 corrugations at 5″ . = 2′ 6″
   13½′
   Y = 6′ + 8′ — ½′ for overlap . . . = 13½′   XY = 182·25 sq. ft.
2. This rate is for a roof on steel members, or for the specification which precludes sheets being screwed to wooden members. If screws G. I. are used instead of hook bolts, the rate would be about Re. 1 less.
3. See notes, Rate 31.

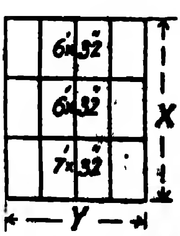
31. Roofing.

N. T. Pattern, C. G. I. sheets 32" ×24-G., P. G. I. rolls 24-G., chock battens 4" ×1½" ×2" excluding planking and ridging.

Station—Naini Tal.

Details of labour and materials per 183 sq. ft.			No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
MATERIALS.				Rs.		Rs.	Rs.
C. G. I. sheets 24-G.							
4×7'×32"=4×22·4 lbs. .	= 89·6						
8×6'×32"=8×19·2 lbs. .	=153·6	lbs.	243·2	12·25	cwt.	26·59	
	243 2						
P. G. I. sheets 24-G. Rolls.							
1×7'×2'=14=1·17 lbs. .	=16 38						
2×6'×2'=24=1·17 ,, .	=28·08						
	44·46	,,	44·46	15 75	,,	5·46	32 05
Chocks, 28×4"×1½"×2"		c.ft	·2	·875	c. ft	·175	
Clips, 1"×⅛"—							
Batton, 28×3" at ·42 lbs. .	=2 94						
Eave, 4×6" at ·42 lbs. .	= 84						
Roll, 4×6" at ·42 lbs. .	= 84						
	4·62	lbs.	4·62	·095	lb.	·44	
Screws.							
3" 1 per chock=4×7=28		Nos.	28	1·375	gross	·267	
1½" 2 per batten clip=2×28=56							
1 per roll sheet =3×4=12							
	68	,,	68	·563	,,	·266	
1¼"—							
1 per sheet . .	=12						
1 per eave clip .	= 4						
1 per roll clip .	= 4						
	20	,,	20	·438	,,	·061	1·209
LABOUR.							
Carpenters		Nos.	2	·75	each	1·50	
Smith		,,	1	·75	,,	·5	
Coolies		,,	3	·25	,,	·75	2·75
							36 009
				10 per cent. labour .			·275
							36 284
Cost per 100 sq. ft.		..	..	..	..	36·284 / 1 83	=19·85 say. Rs. 20

NOTES.—*Area taken.*—X=6'+6'+7'—2×½ for overlaps=18'.



Y=total width of sheets per row	=4×32"=10' 8"	
Add width of battens	=4×1½"= 6"	
Deduct 3" per sheet for rolling	4×3"	=1' 0"
		10'2"

∴ area covered=18×10⅙ . . =183 sq. ft.

2. Weight of C. G. I. sheets 24=G., 10'×32"=32 lbs. or 3·2 lbs. per r. ft. 32" wide.
3. 4 rolls are taken, each 6" wide.

4. Cost of sheets at Calcutta C. G. I. Rs. 9-8-0 per cwt. and P. G. I. Rs. 11 per cwt., cost of carriage to site Rs. 2-12 per cwt.
5. The chock battens are placed at the ends of each sheet, and one in the middle, or 7 per roll.
6. It is almost always possible by using the various market lengths of sheets, and their sub-divisions, and by ranging size of ridging, to avoid wastage. The wastage at hips and valleys is ordinarily negligible.
7. Two eaves clips per sheet are sometimes preferred, clips can often be made from scraps.

32. Roofing.

N. T. Pattern.

As in previous rate but—

(a) P. G. I sheets 24-G. 4′ wide.
(b) P. G. I sheets 24-G. 3′ wide.
(c) Black sheets 24-G. 3′ wide including coal-tarring and 2 coats red oxide paint.
(d) as for (c), but sheets 2′ wide.

Station—Naini Tal.

Details of labour and materials per various areas.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
(a) 294·5 *s. ft.*—			Rs.		Rs	Rs.
Sheets— 10×8′×4′=320×1·17 lbs.=374·08						
Rolls— 2½×8′×2′=40×1·17 lbs =46·8						
420·88	lbs.	420 88	13·75	cwt.	51 7	
Chocks, clips, screws and labour+10% as in previous rate.	..	..	..	..	4 234	
					55 934	
∴ Cost per 100 sq. ft.	..	..	..	..	55 934 / 2·945	=Rs. 19-0-0
(b) 218·5 *sq. ft.*—						
Sheets— 4×8′×3′×8×6′×3′= 240×1·17 lbs.=280·8 lbs.						
Rolls— 1×8′×2′+2×6′×2′= 40×1·17 lbs =46·8 lbs.						
327·6	lbs.	327·6	13 75	cwt.	40 2	
Chocks, etc., as above	..	..	..	..	4·234	
					44·434	
∴ Cost per 100 sq. ft.	..	..	..	..	44·434 / 2 185	=20·3 say Rs. 20-4-0
(c) 161 *sq. ft.*—						
10×6′×3′=180×0·92 lbs.=165·6 lbs.						
Rolls— 2½×6′×2′=30×0·92 lbs.=27·6						
193·2	lbs.	193·2	10 5	cwt.	18 10	
Chocks, etc., as above	..	..	..	..	4·234	
					22·334	
Cost per 100 sq. ft.	..	..	..	..	22·334 / 1·61	=13 85
Coaltarring.	sq. ft.	210×100 / 161	·5	100		0·65
2 Coats red oxide paint	,,	100	1·375	100		1 375
						15·875 say Rs. 16-0-0
(d) 105 *sq. ft.*—						
Sheets— 10×6′×2′=120×0·92 lbs =110·4						
Rolls— 2½×6′×2′=30×0·92 lbs. = 27·6						
138	lbs.	138	10·5	cwt.	12·95	
Chocks, etc., as above	..	..	..	..	4·234	
					17·184	
Cost per 100 sq. ft.	..	..	..	..	17 184 / 1·05	=16·35
Coaltarring	sq. ft.	150×100 / 105	·5	100	..	·714
2 coats red oxide paint . . .	,,	100	1·375	100	..	1·375
						18·4-39 say Rs. 18-8-0

NOTES.—The areas in above rates are worked out [illegible] In (a) there are 2 rows of sheets 8′×4′ and one row 4′×4′.
In (b) 2 rows 6′×3′, and one row 8′×3′.
In (c) 2 rows 6′×3′, and one row 3′×3′.
In (d) 2 rows 6′×2′, and one row 3′×2′.

2. The cost of black sheets at Calcutta Rs. 7-12-0 per cwt. or Rs. 10-8-0 at site.

3. As the rates are worked out for the same station, all on the same lines, and with the current market prices as quoted at the time, they form a useful guide as to the relative cost of the various varieties of sheeting.

(i) C. G. I. sheets 32″×24 G. P. G. I. rolls 24 G.	Rs. 20-0-0 per 100 sq. ft.		
(ii) P. G. I. sheets 24 G. 4′ broad	,, 19-0-0 ,, ,,	N. T. P.	
(iii) P. G. I. sheets 24 G. 3′ broad	,, 20-4-0 ,, ,,	N. T. P.	
(iv) Black sheets 24. G. 3′ broad including coaltarring and painting	,, 16-0-0 ,, ,,	N. T. P.	
(v) Black sheets 24 G. 2′ broad	,, 18-8-0 ,, ,,	N. T. P.	

4. Though (iv) and (v) are cheapest in first cost, periodical repainting does not make them so economical as galvanized sheeting roofs.

5. As battens can be used instead of planking for (i) this form of roof is probably the cheapest.

33. Painting.
Scraping iron roofs.

Station—Solon.

Details of labour and materials per 50,400 sq. ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
MATERIALS.			Rs.		Rs.	Rs.
Steel wire brushes	Nos.	6	1·375	each	8 25	
Scrubbng brushes, large	,,	4	·5	,,	2·00	
Scrapers	,,	3	·813	,,	2·439	12·689
LABOUR.						
Coolie	Nos.	177	·25	each	44·25	
Do.	,,	24	·188	,,	4·5	
Mate	,,	20½	·282	,,	5·78	54·53
						67·219
					10 per cent.	5·453
						72·672
Cost per 100 sq. ft.	..	..	..	..	72·672 / 504	=·144 =Rs. 0-2-3

NOTES.—Materials supplied by the Shalimar Company.

2. This rate is for N. T. Pattern roofing at the time of the quadrennial repainting.

3. The rate depends entirely on the state of the sheets, and the amount of cleaning insisted on in each case. Compare Rate 35, the item for cleaning and scraping contained in it. This rate gives 250 sq. ft. scraped per coolie, and Rate 35, 800 sq. ft.

34. Painting.
Sheet iron roofs.
Shalimar Coy. red oxide ready mixed
One coat.

Station—Solon.

Details of labour and materials per 50,400 sq. ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
MATERIALS..			Rs.		Rs.	Rs.
Red paint, mixed	cwt.	12	28·5	cwt.	342·00	
Brushes, [illegible]	Nos.	5	3·00	each	15·00	
Do., [illegible]	,,	2	2·125	,,	4·25	
Garah, cloth	yds.	8	·125	yd.	1·00	
Kerosine oil	bottles	4	·125	bottle	·5	
Linseed oil	gallon	½	3·00	gallon	1·5	
Paint cans, 7′×5″	Nos.	2	1·313	each	2·626	
Do., 6″×6″	,,	2	1·063	,,	2·125	
Cotton thread	reel	1	·25	reel	·25	
Scaffolding	..	..	..	..	3·00	372·251
LABOUR.						
Painters	Nos.	88	·5	each	44·00	
Coolies	,,	2	·25	,,	·5	
Do.	,,	35	·188	,,	6·563	51·063
						423·1314
					10 per cent.	5·106
						428·42
Cost per 100 sq. ft.	..	..	..	..	428·42 / 504	=·85 =Rs. 0-13-6

NOTES.—This rate was for painting roofs referred to in previous rate.

2. Paint used per 100 sq. ft. covered one coat =2·67 lbs.

3. Area done per painter=572 sq. ft. or per 100 sq. ft. 0·175 painter, and 0·073 coolie. The paint was rather stiff

4. When painting roofs in the neighbouring station of Sabathu, using red oxide powder paint, it was found the average labour required for painting 100 sq. ft. one coat was 0·1 painter, and ·02 coolie.

35. Painting.

Sheet iron roofs.

Kutni red oxide paint, one coat, including cleaning as in quadrennial repairs.

Station—Naini Tal.

Details of labour and materials per 100 sq. ft.			No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
	lbs.			Rs.		Rs.	Rs.
Kutni powder	112	cwt.	1	9·00	cwt.	9·00	
Raw linseed oil, 6 gals.= 9·188 lbs. . .	=55·1	gallons	6	3·829	gallon	23·00	
Boiled linseed oil, 4·5 gals.× 9·438 lbs.	=42·5	,,	4½	3 891	,,	17·59	
	209·6					49·59	
Actually 209 lbs.—							
∴ cost per lb.		..	..	49 59 / 209	..	=·237	
MATERIALS.							
Prepared paint		lbs.	2·88	·237	lb.	·683	
Paint brushes		sq. ft.	..	11 875	52606	·023	·706
LABOUR.							
Mixing and grinding in handmill—Coolie, grinding.		Nos.	2·88 / 86		each	·008	
Coolie, mixing		,	2·88 / 860	·25	,,	·001	
Painting coolie		,,	⅙	·25	,,	·041	·05
CLEANING.							
Steel brushes		sq. ft.	..	7·875	52606	·015	
Coolies		Nos.	⅛	25	each	·03	·045
							·801
						10 per cent.	·008
							·809= Re. 0-13-0

NOTES.—It is essential that this powder be ground and mixed in a paint mill. The supplying firm's specification is to mix 3 gals. of raw oil with 1 cwt. of the powder, and then add as much boiled oil as is required to give the paint the proper consistency. But using a paint mill, it was found that 6 gals. of the raw oil, per cwt. of powder were required to pass the powder through the mill.

2. In this rate a coolie cleans 800 sq. ft. a day or paints 600 sq. ft. Compare previous Rate.

3. In stations where trained painters are not available, coolies are employed. Their task is however only about one-half of that of a trained painter, so the cost is about the same.

4. This rate may be also taken to apply to the 1st coat on new sheets, the second coat costing say 2 annas less.

36. Painting on wood.
Preparation of surface for quadrennial painting.

Station—Sabathu.

Details of labour and materials per 21,660 sq. ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
MATERIALS.			Rs.		Rs.	Rs.
Country soap	seers	8	·5	seers	4·	
Sujji	,,	8	·063	,,	·050	
Garaah cloth	yds.	8	·095	yd.	·75	
Charcoal, to burn off old paint	Mds.	½	1·5	Md.	·75	
Firewood to heat water	,,	4	·56	,,	2·25	
Empty drums, tins for water, etc.	..	..	..	..	1 75	10 00
LABOUR.						
Coolies	Nos.	68	·25	each	17·00	
Mate	,,	6	·75	,,	4·50	21·50
					31 50	
Rate per 100 sq. ft.	..	..	..	..	218 60	=·145 =Rs. 0-2-4

NOTES.—A large barrack done by daily labour.
2. The woodwork cleaned down to a fair surface, not requiring a great amount of old paint to be burnt off.

37. Painting on wood.
Priming coat.

Station—Naini Tal.

Details of labour and materials per 100 sq. ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
			Rs.		Rs.	Rs.
Red lead	lbs.	7	·188	lb.	1·316	
Boiled linseed oil—						
Weight 7 lbs. $+\frac{9·438}{2}=7+4·719$ $=11·719$ lbs.	gallon	½	3·891	gallon	1·946	
					3 262	
∴ Cost per lb	..	..	..	$\frac{3·262}{11·719}$	=·278	
MATERIALS.						
Mixed paint	lbs.	4·00	·278	lb.	1·112	
Share of brushes	,,	..	..	,,	·08	1·192
LABOUR.						
Coolie painter	Nos.	·91	·25	each	·23	·23
						1·422 =Rs. 1-7-0

NOTES.—Work on new chirwood by daily labour.
2. The quantity required per 100 sq. ft. varies very much with the wood. The Shalimar Company give as a guide that the quantities required for teak and deal are as 1·8 to 2·0, see General notes, page 244.
3. There are many specifications for priming paints, and it is probably best to use a ready mixed paint such as that supplied by the Shalimar Company.
4. The following are the quantities given by Hurst for—

Knotting and stopping per 900 sq. ft.
Knotting red lead ·3 lb.
Glue ·3 lb.
Stopping—
putty ·4 lb.
pumice stone ·5 lb.
glass paper 1 quire.

38. Painting on wood.

Station—Solon.

Details of labour and materials per 31,400 sq. ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
			Rs.		Rs.	Rs.
MATERIALS.						
Chocolate paint, ready mixed	cwt.	12	25·5	cwt.	306·00	
Brushes, ⅜	Nos.	8	2·125	each	17·00	
Do., 2	„	6	1·5	„	9 00	
Garah cloth	yds.	8	·125	yds.	1 00	
Kerosine oil	bottles	8	·125	bottle	1·00	
Boiled linseed oil	gallons	¼	3 00	gallon	·75	
Paint can, 7″×5″	Nos.	3	1·313	each	3 939	
Do., 6″×6″	„	3	1 063	„	3 189	
Cotton thread for brushes	reel	1	·25	„	·25	
Scaffolding	..	..	..	..	3·00	345 128
Washing down.						
Scrubbing brushes, large	Nos.	4	·5	each	2·00	
Do. small	„	4	·313	„	1·25	
Empty drums	„	2	·5	„	1 00	
Scrapers	„	2	·813	„	1·626	5 876
LABOUR.						
Painting.						
Painters	Nos.	104	·5	each	52·00	
Coolies	„	18	·25	„	4·50	
Do.	„	18	·188	„	3·375	59·875
Washing down.						
Coolies	Nos.	88	·25	each	22·00	
Do.	„	8	·188	„	1·5	
Mate	„	5	·282	„	1·41	
Do.	„	4	·375	„	1·5	26·41
				10 per cent. labour		437·289 8·62
						445·909
Cost per 100 sq. ft.	..	..	..	..	445·909 / 314	=1·42 =Rs. 1-7-0

NOTES.—The surface painted consisted of 25,000 sq. ft. of rough weather boarding, and 6,400 sq. ft. of ordinary chir wood work.

2. The amount of paint used per 100 sq. ft. of surface painted was 4·28 lbs. This is high.
3. The area painted per painter was 300 sq. ft. a day, or ·33 painter and ·115 coolie per 100 s. ft.
4. Very little scraping was done, the walls being scrubbed with brushes.
5. All brushes, cans, etc., of English make.
6. This rate gives annas 2 for cleaning, and Rs. 1-5 for painting.

General notes on painting rates.

The painting rates are the most difficult to solve satisfactorily. First, the amount of cleaning and scraping required often varies considerably, in repainting old woodwork, iron roofs, etc. Secondly, the quantity of paint required per 100 sq. ft. will depend upon the absorbent nature of the surface painted, and the skill of the painter. Thirdly, the area painted per man per day depends both on the skill of the man, and the nature of the surface to be painted and its position. A man will paint much more quickly on a plain surface than he will on doors, windows, jaffri work, etc., and more quickly on a boarded wall than on a ceiling. Frequent fluctuations in the cost of linseed oil also affect the rates largely.

2. The following may be taken as the tasks for an ordinary painter :—

(*a*) sheet iron roofs, if the paint is running freely 1,000 sq. ft.; if the paint is thick about 600 sq. ft.;

(*b*) on a plain surface, such as boarded wall or the sides of a reservoir, 300 sq. ft.;

(*c*) doors and windows, pillars, rafters, jaffree work, an average for all kinds of work in a big barrack, 150 sq. ft.

In addition allow 1 coolie to every 5 or 6 painters.

3. As regards proportions for paints, and the amount required per 100 sq. ft., the following table shows the Shalimar Company's figures :—

Description of paint.	Thinnings. Boiled linseed oil 3; turps 1; in lbs. per cwt of stiff paint.	Equivalent of col. 2 in gallons.		Total weight of mixed paint. i.e., 1 cwt. + col. 2.	lbs. of mixed paint per 100 sq. ft.			
		Boiled linseed oil.	Turpentine.		Priming coat new wood, i.e., 1st coat.	2nd coat, new wood.	1st coat old rough work, iron or wood.	2nd coat old rough work, iron or wood and smooth iron.
1	2	3	4	5	6	7	8	9
Shalimar—								
Special White, best	45	3·66	1·22	157	3·5	1·92	1·92	1·75
Red oxide, best .	32	2·62	0·87	146	3·5	1·92	1·92	1·75
Green paint, best .	18	1·47	0·49	130	3·5	1·92	1·92	1·75
Chocolate, best .	30	2·46	0·82	142	3·5	1·92	1·92	1·75
Slate colour, best .	23	1·85	0·62	135	3·76	2·06	2·06	1·88

4. Ready mixed paints are largely used, as though their cost is higher than that of paint ground in oil and mixed locally in a paint mill, possible mistakes

and fraud in mixing are more easily avoided, and the ingredients are more intimately incorporated than it is possible to ensure by local mixing.

5. It will generally be found in practice that these figures for the amount of paint per 100 sq. ft. are low. This is due partly to lack of skill in application; and to obtain a reliable rate for each station experiments should be carried out on the surfaces and material used locally for which the rate is required. The figures given in the above detailed rates will illustrate this. As a further instance, at Ranikhet it was found that for painting chir wood in quadrennial repairs, 1 coat, 2·75 lbs. of ready mixed Shalimar paints were required per 100 sq. ft.; less absorbent woods such as teak and sal would require less paint and the quantities required would approximate more nearly to the figures given in the table.

6. The following is the short table of factors given by the Shalimar Company to be used for obtaining the quantities of mixed paint of their manufacture required on certain surfaces, the quantity of paint required on smooth iron (col. 9 of table in paragraph 3) being taken as unity:—

Surface.	1st coats.	2nd coats.
Teakwood	1·8	1·1
Deal	2·6	1·2
Iron	1·1	1·0

7. For *copal varnish*, the approximate figures on a deodar ceiling, after knotting and stopping are:—

Area covered per gallon	1st coat	520 sq. ft.
	2nd coat	670 „
	3rd coat	1,000 „

39. Oiling woodwork.

Station—Bareilly. **New sal wood, two coats.**

Details of labour and materials per 1,933 sq. ft.		No. or quantity.	Rate Cost.	Rate Per	Amount.	Total.
MATERIALS.			Rs.		Rs.	Rs.
Boiled linseed oil	gallons	4	4·408	gallon	17·632	
Brushes	Nos.	2	·938	each	1·875	19·507
LABOUR.						
Carriage, coolies	Nos.	$\frac{1}{3}$	·188	each	·063	
Oiling, gharamies	„	11	·25	„	2·75	2·813
						22·32
10 per cent. labour	..	..	..	..	..	·28
						22·6
Cost per 100 sq. ft.	..	..	..	..	22·6 / 19·33	=1·17
						say 1st coat Re. 0-10-6. 2nd coat Re. 0-8-6.

NOTES.—It will be noted that the cost of the linseed oil is very high: this rate fluctuates a good deal.
2. For oiling mud plaster with raw linseed oil, about 1 gal. per 250 sq. ft. is required for one coat.
3. Crude Burma oil is much cheaper than linseed oil, and may often be used in its stead, for wood work.

40. Laying cast iron pipes, 6″ diameter, spigot and socket joints.

Station—Bombay.

ails of labour and materials per 100 r. ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
MATERIALS.			Rs. A. P.		Rs. A. P.	Rs. A. P.
C. I. pipe, 6″ dia.	cwts	28	7 0 0	cwt.	196 0 0	
Lead for joints	lbs.	82	0 2 6	lb.	12 13 0	
Rope	,,	4	0 12 0	,,	3 0 0	
Carriage and carting	cwts.	28	0 2 0	cwt.	3 8 0	
Sundries such as wood, charcoal, etc.	..	..	..	.	3 10 0	218 15 0
LABOUR.						
Excavating trenches	c. ft.	825	1 0 0	100	8 4 0	
Filling in trenches	,,	825	0 6 0	100	3 1 0	
Fitters	No.	2	1 0 0	each	2 0 0	
Blacksmith	,,	½	0 12 0	,,	0 6 0	
Bellows boy	,,	½	0 4 0	,,	0 2 0	
Coolies	,,	9	0 4 0	,,	2 4 0	
Women	,,	2	0 2 6	,,	0 5 0	
Watchman	,,	1	0 4 0	,,	0 4 0	
Repairs to roads	..	..	.	.	8 0 0	
Sundries	..	..	.	..	2 0 0	27 2 0
				TOTAL FOR 100 r. ft.		246 1 0
				TOTAL PER r. ft.		2 7 0

41. Laying galvanised wrought iron piping, 1″ diameter.

Station—Bombay.

Details of labour and materials per 100 r. ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
MATERIALS.			Rs. A. P.		Rs. A. P.	Rs. A. P.
W. I. pipe, 1″ dia.	r. ft.	100	0 5 0	ft.	31 4 0	
Carriage	..	..	..	..	1 8 0	
Sundries, oil, etc.	..	..	..	..	0 4 0	33 0 0
LABOUR.						
Excavating trenches	c. ft.	100	1 0 0	100	1 0 0	
Filling in trenches	,,	100	0 6 0	100	0 6 0	
Fitter	No.	⅜	1 0 0	each	0 6 0	
Coolies	,,	1½	0 4 0	,,	0 6 0	
Watchman	,,	¼	0 4 0	,,	0 1 0	
Sundries	..	..	..	..	0 4 0	2 7 0
				TOTAL FOR 100 r. ft.		35 7 0
				Cost per r. ft.		0 6 0

42. Road work.

Consolidation of kunkur for renewals.

Station—Bareilly.

Details of labour and materials per 1,000 c. ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
			Rs.		Rs.	Rs.
Picking up road.						
Beldars	Nos.	4·45	·188	each	·84	
Making side bunds.						
Bhisti	Nos.	2 20	·22	each	·484	
Beldars	„	4·40	·188	„	·83	
Coolie	„	1 1	·095	„	·105	
Carrying kunkur from stacks and spreading.						
Beldars	Nos.	2 20	·22	each	·484	
Coolies	„	6	·157	„	·942	
Do.	„	6	·125	„	·75	
Ramming with hand rammers.						
Mate	Nos.	2·20	·375	each	·83	
Beldars	„	17·7	·22	„	3·89	
Bhistis	„	6·65	·22	„	1·46	
Chowkidar	„	4·45	·188	„	·84	
Kerosine oil for night	Bottle	10	·11	„	1·10	12·555
Cost per 100 c. ft.	..	..	..	..	..	1·25 =Rs. 1-4-0

Notes.—Work done departmentally. Metal spread 4½" thick which rams down to about 3".
2. The question of proximity of water affects the rate materially. Also whether consolidation is done in the dry or wet weather.
3. The above is the rate for work in dry weather with water close at hand.

43. Roadwork.
Collection of stone metal.

Station—Chakrata Cart Road.

Details of labour and materials per 100 c. ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total
(a) Collecting stone.			Rs.		Rs.	Rs.
Coolies	Nos.	8	·125	each	1·00	
Breaking stone.						
Coolies	Nos.	14	·25	each	3 5	
Mate and munshis	"	1	·5	"	·5	
Baskets	"	1	·125	"	·125	
Rope	chtks.	10	·800	md.	·125	5 25
			10 per cent. on whole			52
						5 77 say Rs. 5-12-0
(b) Collecting stone and loading carts.						
Coolies	Nos.	4	·25	each	1 00	
Carts	"	2	1·375	"	2 75	
Breaking stone.						
Coolies	Nos.	12	·25	each	3·00	
Mates and munshis	"	1	·5	"	·5	7·25
			10 per cent. on whole			·72
						7·97 say Rs. 8-0-0
(c) Collecting stone.						
Coolies	Nos.	5	·125	each	·625	
Breaking stone.						
Coolies	Nos.	11	·25	"	2·75	
Mates and munshis	"	1	·5	"	·5	
Baskets and ropes	..	..	..	..	·25	4·125
			10 per cent. on whole			·413
						4 538 say Rs. 4-8-0

NOTES.—The above are the rates for the varying conditions in 3 different miles. Gauge of metal 1½"; the tasks for breaking to gauge are respectively 7½, 8¼, and 9 c. ft. a day per coolie, according to the hardness of the stone.

44. Road work.
Consolidation of stone metal by 6 ton steam roller.

Station—Chakrata Cart Road.

Details of labour and materials per 15,840 c. ft.		No. or quantity.	Rate. Cost.	Rate. Per	Amount.	Total.
			Rs.		Rs.	Rs.
Fuel, hard wood	c. ft.	500	15·00	100	75·00	
Oil, cylinder	lbs.	6	·266	lb.	1·596	
Do. lubricating	„	19	·188	„	3 563	
Cotton waste	„	24	·225	„	5·400	
Indian grease	„	2	·25	„	·5	
Packing cotton	„	3	1 00	„	3·00	
Kerosine oil	bottle	12	·125	each	1·5	
Soap, Indian	lbs.	2	·125	lb.	·25	
Matches	doz	1	·188	doz.	·188	
Rope	mds.	1½	8·00	md.	12 00	
Kerosine oil tins	Nos.	10	·25	each	2 5	
Soothe	lbs.	2	·75	lb.	1 5	
Wool for oil cups	„	½	2 00	„	1 00	107·997
LABOUR.						
Scoring road, coolies	No.	93	·25	each	23·25	
Spreading metal, coolies	„	200	·25	„	50 00	
Do. earth, coolies	„	330	·25	„	82·50	
Watering wheels of roller, coolies	„	120	·25	„	30·00	
Splitting wood, coolies	„	17	·25	„	4·25	
Repairing road, coolies	„	36	·25	„	9·00	
Carrying wood, coolies	„	58	·25	„	14·5	
Do. pipes, do.	„	19	·25	„	4·75	
Keeping water channels clear, etc., coolies	„	40	·25	„	10·00	
Engine driver	„	12	1·5	„	18·00	
Fireman	„	12	·313	„	3·75	
Chowkidar	„	12	·25	„	3·00	
3 mates at 0-8-0, 0-6-0 and 0-6-0 = Rs. 1-4-0.	„	12	1·25	„	15·00	268·00
Add one day for general repairs to mile and one day for cleaning up engine.	..	..	..	..	14·00	14·00
						389·997
Cost per 100 c. ft.	..	..	..	..	$\frac{389·997}{158·4}$	= 2·46 say Rs. 2-8-0

NOTES.—Breadth of road 9′ metal spread 4″ deep, The whole mile took 12 days to consolidate, and the two days extra allowed at end of rate. This gives $\frac{5280}{12}$ = 440 sq. ft. a day consolidated, with water carried alng roadside drains to site.

2. This is a daily labour rate with careful supervision and a considerable amount of drive.

Rates for work in prin

(Corrected to

Item No.	Nature of work.	Per	1st Division. Peshawar.	1st Division. Kohat.	2nd Division. Rawalpindi.	2nd Division. Murree.	3rd Division. Lahore.	3rd Division. Ambala.	4th Division. Quetta
	Earthwork.								
1	Excavation in foundations, ordinary soil	1,000 c. ft.	4/-/-	3/8/-	4/-/-	5/-/-	5/-/-	3/-to 5/-	5/4/-
2	Excavation in soft rock .	100 c ft	1/8/-	1/8/-	..	..	..	..	2/8/-
3	„ hard rock .	„	2/-/-	2/8/-	..	..	..	..	3/8/-
	Concrete.								
4	Brick ballast in lime . .	„	18/-/-	..	..	..	21/8/-	23/4/-	..
5	Stone ballast in lime . .	„	20/-/-	19/-/-	16/-/-	16/-/-	..	..	21/-/-
6	Cement concrete 1 2 : 4 .	„	..	62/8/- (1: 2 : 6)	66/8/-	75/-/-	70/-/-	..	80/-/-
	Brickwork.								
7	In lime, 1st class . .	„	29/-/-	34/-/-	30/-/-	..	29/-/-	30/-/-	37/-/-
8	„ 2nd „ . .	„	25/-/-	31/-/-	24/4/-	..	26/4/-	26/-/-	35/-/-
9	In clay, 1st „ . .	„	21/8/-	28/-/-	21/-/-	..	21/12/-	22/8/-	28/-/-
10	„ 2nd „ . .	„	19/-/-	25/-/-	17/-/-	..	19/-/-	18/8/-	26/-/-
11	In cement mortar 1 : 3, 1st class.	„	..	68/8/- (1 : 2)	51/12/-	..	50/-/-	60/-/-	55/-/-
12	In lime, in arches . .	„	36/-/-	41/-/-	38/-/-	..	33/8/-	37/-/-	46/-/-
13	Sundried brickwork . .	„	5/-/-	6/8/-	5/-/-	..	7/-/-	7/8/-	8/-/-
	Stone Masonry.								
14	Coursed rubble in lime .	„	20/-/-	35/-/-	26/-/-	27/-/-	..	..	38/8/-
15	„ in clay .	„	15/-/-	24/-/-	17/-/-	17/-/-	..	..	20/-/-
16	Dry rubble masonry, rough	„	6/-/-	8/-/-	12/-/-	12/-/-	..	..	9/-/-
17	Dressed stone in bed-plates, etc.	c. ft.	1/8/-	1/-/-	1/-/-	1/-/-	2/8/-	..	2/14/-
	Plaster and Pointing.								
18	Lime plaster on brickwork .	100 s. ft.	3/-/-	4/-/-	2/8/-	2/8/-	2/8/-	2/12/-	4/14/-
19	Cement plaster ½", 1 : 2 .	„	6/9/- (1 : 1)	8/-/-	6/-/-	7/-/-	5/-/-	6/-/-	4/8/- (1 : 3)
20	Mud plaster and Leeping .	„	-/10/-	-/9/-	-/8/-	-/10/-	-/8/-	-/8/-	-/1[illegible]/-
21	Lime pointing brickwork .	„	2/-/-	2/-/-	2/-/-	..	1/14/-	1/12/-	2/10/-
22	Cement pointing, 1 : 3	„	3/12/- (1 : 1)	4/-/-	3/-/- (1 : 2)	3/4/- (1 : 2)	3/-/-	2/8/- (1 : 2)	8/4/-

cipal Stations in India.

July 1913.)

5th Division.		6th Division.		Aden.	7th Division.		8th Division.		9th Division.		
Mhow	Jabalpur.	Poona	Bombay		Meerut.	Bareilly.	Lucknow.	Fort William.	Secunderabad	Madras.	Bangalore.
4/12/-	5/-/-	10/-/-	15/-/-	7/8/-	2/8/-	5/-/-	5/-/-	5/-/-	4/-/-	4/8/-	5/-/-
2/8/-	..	2/-/- to 5/-/-	3/8/-	3/8/-	..	..	..	..	1/8/-	..	..
5/-/- to 8/-/-	4/8/-	8/-/-	8/-/-	10/-/-	..	..	..	..	9/-/-	..	7/-/-
..	..	..	..	..	14/2/-	15/12/-	..	..	..	16/-/-	..
16/12/-	15/-/-	18/8/-	20/-/-	15/8/-	..	..	22/-/-	38/-/-	16/-/-	18/-/-	17/-/-
..	..	55/-/-	42/-/-	60/-/-	..	..	88/-/-	70/-/- (1 : 2 . 5)	..	79/-/- (1 : 1 : 4)	..
28/8/-	27/-/-	29/-/-	40/-/-	..	25/8/-	21/12/-	27/-/-	32/-/-	24/-/-	33/-/-	26/-/-
26/8/-	..	26/-/-	34/-/-	..	20/8/-	19/8/-	24/-/-	27/-/-	19/-/-	29/-/-	20/-/-
23/8/-	23/-/-	18/-/-	..	..	18/8/-	16/4/-	21/-/-	24/-/-	18/-/-	..	20/4/-
21/8/-	21/8/-	16/-/-	..	..	13/-/-	13/14/-	18/-/-	20/-/-	14/-/-	..	15/-/-
62/-/- (1 : 2)	40/-/-	51/-/-	54/-/-	..	..	53/-/-	45/-/-	50/-/-	..	..	..
38/8/-	32/-/-	30 -/-	45/-/-	..	30/-/-	26/- -	32/-/-	41/-/-	30/-/-	39/-/-	32/-/-
7/8/-	5/8/-	..	..	12/-/- to 24/-/-	5/-/-	4/-/-	4/-/-	6/-/-	6/-/-	7/-/-	6/4/-
..	26/-/-	30/-/-	26/-/- to 34/-/-	50/-/-	..	..	..	33/-/-	24/-/-	150/-/-	25/-/-
..	20/8/-	15/-/-	16/-/-	46/-/-	..	..	..	22/-/-	19/-/-	145/-/-	21/-/-
..	12/-/-	..	13/-/-	8/-/-	..	..	..	..	7/-/-	27/-/-	..
1/-/-	1/8/-	..	1/12/- to 2/12/-	1/8/-	2/8/-	2/-/-	1/14/6	2/8/-	1/-/-	2/12/-	..
3/-/-	2/12/-	6/8/-	3/-/-	4/-/-	3/-/-	2/4/-	3/-/-	3/8/-	3/8/-	1/8/-	1/8/-
6/-/-	6/8/- (½")	8/-/- (½")	9/8/- (½")	6/-/-	7/-/-	..	7/12/-	4/10/-	..	4/10/-	5/8/-
-/12/-	1/-/-	1/8/-	1/1/-	2/-/- to 2/12/-	-/6/-	-/6/-	-/10/-	-/10/-	1/-/-	-/6/-	-/6/-
1/8/-	1/12/-	2/8/-	1/14/-	..	1/12/-	1/6/-	1/12/-	1/8/- to 2/8/-	1/14/-	1/4/-	1/4/-
3/-/-	4/-/- (1 : 2)	3/4/-	4/8/-	..	3/-/-	..	2/8/- (1 : 1)	3/8/- (1 : 2)	3/13/- (1 : 1)	3/-/-	..

Rates for work in prin

(Corrected to

Item No.	Nature of work.	Per	1st Division.		2nd Division.		3rd Division.		4th Division.
			Peshawar.	Kohat	Rawalpindi.	Murree.	Lahore.	Ambala.	Quetta.
	White and Colourwash.								
23	Scraping walls . . .	100 s. ft	-/1/6	-/1/6	-/1/-	-/1/-	-/1/-	..	-/1/-
24	Whitewash, 1 coat . .	"	-/1/3	-/2/-	-/1/3	-/1/3	-/1/6	-/1/8	-/2/-
25	" 3 coats . .	"	-/3/-	-/4/-	-/3/9	-/3/9	-/3/6	-/4/-	-/5/-
26	Colourwash, 2 coats and 1 coat whitewash.	"	-/5/6	-/9/-	-/4/6	-/5/3	..	-/5/6	-/7/6
	Woodwork.								
27	Woodwork wrought, framed and fixed.	c. ft.	2/6/-d	2/6/-d	5/-/-t 1/-/-c 2/8/-d	2/-8/-d	1/8/-k 2/6/-d	1/10/-c 3/-/-d	5/-/-t 1/6/-c 2/-/-k 2/8/-d
28	Doors, panelled and framed, 1½".	s. ft.	1/-/-d	1/2/-d	-/12/-d	-/12/-b	-/12/-d	-/14/-d	1-/6/-t -/13/-d
29	Doors, battened, 1½" . . (t=teak : s=sal : d=deodar : c=chir : k=kail : j=jarrah . b=bair : bn=benteak : ct=country teak).	"	-/10/-d	-/12/-d	-/9/-d	-/9/-b	-/10/-d	-/13/-d	-/11/-d
	Ironwork.								
30	In bolts, straps, etc. . .	cwt.	18/-/-	15/-/-to 19/-/-	16/6/6	17/12 -	18/-/-	16/-/-	21/-/-
31	In trusses	"	12/-/-	..	12/5/-	13/11/-	..	15/-/-	17/12/-
32	R.S. beams, fixed . .	"	9/-/-	..	8/3/-	9/3/3	..	10/-/-	8/12/-
	Painting, etc.								
33	Painting, silicate, 1 coat .	100 s. ft.	1/-/-	1/8/-	-/15/-	1/1/-	1/-/-	-/15/-	-/10/6
34	" 2 coats and 1 priming coat.	"	3/-/-	3/-/-	2/11/-	3/1/-	2/8/-	2/4/-	2/8/-
35	Painting, red oxide, 1 coat .	"	1/4/-	1/-/-	-/10/-	-/12/-	-/12/-	-/6/-	-/6/-
36	" " 2 " .	"	2/4/-	1/12/-	..	..	1/4/-	-/10/-	1/-/-
37	Varnish, copal, 1 coat .	"	-/15/-	1/2/-	1/-/-	1/2/-	1/-/-	-/10/-	1/5/-
38	" 2 " .	"	1/14/-	2/-/-	1/12/-	1/15/-	1/12/-	1/8/-	2/-/-
39	Coaltarring, 1 coat . .	"	-/12/-	-/12/-	-/8/-	-/9/-	-/10/-	-/8/-	-12/-
40	" 2 " . .	"	1/5/	1/4/	1/-/	1/2/-	1/-/-	1/14/-	1/6/-
41	Oiling woodwork, 1 coat .	"	-/4/-	.	..	..	-/8/-	..	..
42	Solignum, 1 coat . .	"	..	..	-/13/-	-/14/-	-/11/-	..	..

cipal Stations in India.

July 1913.)

5th Division.		6th Division.			7th Division.		8th Division.		9th Division.		
Mhow.	Jabalpur.	Poona.	Bombay	Aden.	Meerut.	Bareilly	Lucknow.	Fort William.	Secunderabad	Madras.	Bangalore.
-/2/-	-/1/-	-/1/6	..	-/3/-	-/1/6	-/2/-	-/2/-	-/2/6	-/1/-	-/5/-	..
-/1/6	-/2/-	-/2/-	-/3/-	-/2/-	..	..	-/1/7	-/2/2	..	-/1/6	-/1/9
-/3/6	/4/-	-/6/-	-/5/-	-/5/-	-/3/6	-/3/-	-/3/7	-/5/4	-/3/2	..	..
-/5/-	..	-/7/-	..	-/7/-	..	..	-/4/10	-/8/-	-/4/-	..	-/5/-
4/8/- t	4/-/- t	4/8/- t	3/12/-t-	7/-/- t	4/-4/ s	4/8/- t	6/4/- t	2/12/- j 4/-/- t	5/4/-t	4/-/- t	3/12/- t
4/-/- s	3/4/- s	3/-/- j	2/12/- j	4,-/- bn	2/8/- j	3/12/- s	3/8/- s	3/4/- s	3/12/-j	..	..
1/-/-ct	1/3/- ct	-/15/- t	1/4/- t	2/-/- t 1/6/-bn	1/2/- t 1/-/- d	1/2/- t 1/-/- s	1/4/- t	/15/- t	1/2/-t	-/12/-t	-/12/- t
-/15/-ct	-/15/-ct	-/11/-t	1/-/- t	-/15/ bn (1")	1/-/-d (2")	-/14/- s	1/12/- t	-/11/- t (1")	-/14/-t (1")	-/10/-t	-/11/6t
20/-/-	18/8/-	21/-/-	21/-/-	21,-/-	17/-/- to 20/-/-	17/-/- to 20/-/-	17/8/-	14/-/-	21/ /-	17/-/-	17/8/-
15/-/-	13/-/-	12/-/-	14/4/-	..	13/-/-	13/-/-	15/-/-	12/8/-	..	12/-/-	15/-/-
8/8/-	9/2/-	7/-/- to 9/-/-	10/-/-	10/8/-	8/8/-	8/-/-	10/-/-	7/-/-	8/-/-	9/8/-	10/8/-
1/8/-	1/8/-	1/5/-	1/4/-	1/4/-	-/12/-	-/12/-	-/14/-	1/4/-	1/4/-	1/2/-	-/13/-
3/-/-	3/4/-	3/1 -	2/12/-	3/5/-	2/-/-	2/4/-	2/8/-	2/12/-	3/-/-	2/4/-	1/14/-
..	1/4/-	-/13/-	..	-/11/-	..	..	-/10/-	-/12/-	-/14/-	-/9/-	..
..	2/-/-	..	..	1/6/-	..	..	1/2/-	1/6/-	1/8/-	-/15/-	..
1/8/-	1/12/-	1/-/-	1/12/-	1/6/-	-/14/-	-/14/-	1/6/-	1/8/-	..	1/-/-	1/6/-
2/4/-	2/12/-	2/-/-	2/8/-	2/10/-	1/8/-	1/8/-	2/2/-	2/12/-	..	1/12/-	2/-/-
..	-/11/-	..	-/6/-	-/7/-	-/10/-	-/6/-	-/8/-	-/6/-	1/-/-	-/8/-	-/4/-
..	1/1/-	..	-/10/-	-/10/-	1/-/-	-/12/-	-/14/-	-/10/-	1/8/-	-/12/-	-/8/-
-/6/-	-/6/-	-/4/-	-/8/-	-/5/-	..	-/6/-	-/8/-	..	..	-/8/-	-/8/-
-/11/-	1/8/-	..	..	3/-/-	..	..	-/15/-	..	..	..	4/-/- (2 coats)

Rates for work in prin

Corrected to

Item No.	Nature of work.	Per	1st Division.		2nd Division.		3rd Division.		4th Division.
			Peshawar.	Kohat.	Rawalpindi.	Murree.	Lahore.	Ambala.	Quetta.
	Roofing.								
43	Double Allahabad tiling	100 s. ft.	20/10/-	..	21/12/-	..	32/4/-	24/-/-	..
44	Single " "	"	9/14/-	..	11/4/-	..	16/12/	12/-/-	..
45	Mangalore tiling	"	..	..	17/-/-	..	..	..	..
46	Corr. iron 24 G.	"	..	23/-/-	19/12/-	20/12/-	23/-/-	..	/24/-/-
47	" 22 G.	"	..	..	23/-/-	..	27/-/-	30/-/-	28/ /-
48	Naini Tal roofing, 22 G.	"	23/-/-	32/-/-	30/-/-	31/4/-	..	25/-/- (24 *g*)	32/-/-
49	Terrace, 3", on tiles	"	11/12/-	16/-/-	8/-/-	8/-/-	..	..	..
50	Mud, 6", on tiles	"	10/-/-	11/-/- (4")	7/8/-	..	9/-/- (4")	..	..
	Flooring.								
51	Brick on edge	100 s. ft.	14/-/-	14/8/-	12/8/-	..	13/8/-	12/8/-	18/8/-
52	Brick flat	"	10/-/-	10/8/-	8/4/-	..	8/8/-	8/8/-	12/8/-
53	Flagged, 1½" to 3" (above exclude concrete).	"	30/-/-	..	31/-/-	..	..	36/-/-	47/8/-
54	Terraced, (i) 4" : (ii) 6"	"	..	10/-/- (i)	..	..	12/12/- (ii)	..	13/-/- (ii)
55	Boarded 1½": (i) butt jointed: (ii) tongued and grooved: *t*=teak. *d*=deodar: *b*=bair. *d*=deal. *ct*=country teak.	"	31/-/- *d*; 35/-/- *d*	..; 36/-/- *d*	.; ..	20/-/- *b*; 24/-/- *b*	31/4/- *d*; 36/-/- *d*	..; ..	40/-/- *d*; 52/-/- *d*
56	Cement concrete, 1" on 3" lime concrete.	"	21/-/-	25/-/-	..	..	..	..	..
	Ceilings.								
57	Wooden (i) ½". (ii) ¾". Letters as in 55.	100 s ft.	30/-/- (ii) *d*	..	24/8/- (ii) *d*	1" rebated. 17/4/- *b*	17/4/- (i) *p*	16/-/- (i) *p*	18/-/- (i) *p*
	Road work.								
58	Collection of (*a*) kunkur or (*b*) stone metal.	100 c. ft.	9/12/- (*b*)	at quarry 3/8/- (*b*)	8/-/- (*b*)	4/8/- (*b*)	..	14/-/- (*a*) 12/-/- (*b*)	7/-/- (*b*)
59	Consolidation or (*a*) kunkur or (*b*) stone metal.	"	3/14/-	2/12/-	2/8/-	2/8/-	..	1/8/- (*a*) 1/12/- (*b*)	3/2/-

cipal Stations in India.

July 1913.)

5th Division.		6th Division.		Aden.	7th Division.		8th Division.		9th Division.		
Mhow.	Jabalpur.	Poona.	Bombay.		Meerut.	Bareilly.	Lucknow.	Fort William.	Secunderabad.	Madras.	Bangalore.
..	21/8/-	..	..	..	17/8/-	16/8/-	20/-/-	..	..	..	..
..	11/4/-	..	..	..	9/8/-	9/-/-	10/-/-	..	..	..	..
24/-/-	15/-/-	18/-/-	9/8/-	24/4/-	..	..	..	18/8/-	15/-/-	16/-/-	14/-/-
21/-/-	..	21/-/-	21/-/-	21/8/-	..	..	25/-/-	24/8/-	..	20/-/-	20/-/-
.	..	23/-/-	24/-/-	..	..	26/-/-	29/-/-	27/8/-	27/-/-	25/-/-	24/12/-
..	..	..	..	..	..	..	..	..	..	..	..
24/-/- (on arches).	22/-/- (4")	..	..	..	10/8/- (4")	5/4/-	8/-/-	26/-/- (4" on 2 layers of tiles).	25/-/- (Madras terrace)	..	27/-/- (Madras terrace).
..	..	..	..	..	..	..	..	..	..	..	..
11/5/-	11/-/-	..	..	..	12/8/-	10/8/-	13/-/-	14/8/-	..	..	..
8/13/-	9/-/-	..	..	..	7/12/-	7/-/-	9/8/-	11/-/-	..	..	..
..	16/8/-	20/6/-	30/-/-	..	27/-/-	23/-/-	25/-/-	..	15/-/- to 29/-/-	20/8/- to 33/8/-	13/8/ to 17/8/
..	10/-/- (i)	..	..	12/8/- (ii)	5/-/- (3")	6/-/- (4½")	9/-/- (4½")	16/-/- (ii)	..	..	6/4/- (i)
..	..	..	26/-/- p	..	29/-/- d	..	..	..	..	..	..
36/-/- c	50/-/- c 68/12/- (t)	..	28/8/- p	..	..	..	..	60/-/-	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..
15/12/- (i) p	15/-/- (i) p	15/-/- (i) p	..	17/-/- (i) p	18/8/- (i) p	15/-/- (i) p	20/-/- (i) p	28/2/- (i) p	27/-/- (i) t	butt joints. 21/-/- (i) t	butt joints. 21/-/- (i) t
4/-/- (b)	5/-/- (b)	..	9/-/- (b)	6/-/- (b)	7/-/- (a)	9/8/- (a)	8/-/- (a)	11/-/- khoa 23/-/- (b)	1/12/10 (b)	10/8/-	7/-/-
2/2/-	2/-/-	..	1/8/- 100 s.ft.	8/14/- 1,00 s.ft.	1/-/-	1/4/-	1/8/-	1/8/- khoa 2/8/- (b)	1/2/-	1/5/-	-/4/- 100 s.ft.

SECTION VII.

Miscellaneous.

TRAVERSING.

Objects. In the Military Works Services traversing is generally required in connection with the demarcation of Cantonment or Zone boundaries. The objects to be attained are (1) to get an accurate and permanent record of the positions of the pillars so that any pillar can be subsequently refixed within a foot or two, (2) to map the boundary accurately on the Cantonment map, and (3) to obtain the data required for the notification of the boundary in the Gazette.

2. The points requiring attention may be classed under the following heads:—

(*a*) Instrumental.
(*b*) Angular measures.
(*c*) Linear measures.
(*d*) Recording observations in the Field book.
(*e*) Computation of results.

Instrumental. 3. The theodolite used must be put in good order to start with. See therefore to the following points:—

(*i*) The upper and lower plates must revolve freely—if not the axles want oiling.
(*ii*) The clamping arrangements must be in good order and the slow motion screws must work easily and without appreciable lost motion or backlash.
(*iii*) The levelling screws must be free from shake and yet not too stiff.
(*iv*) The tripod itself must be stiff and free from shake.

The last two points can best be tested by erecting the instrument, focussing on and intersecting a well defined object and clamping both plates. Then press the telescope firmly and gently to either side and note whether the object remains intersected after the pressure is removed. If not there is a slack screw somewhere which needs adjustment.

Parallax. It is also of course essential to get rid of parallax before commencing work. This is a simple matter if carried out as follows. Without attempting to focus the telescope turn it towards the sky, so that there is a well illuminated field with no object in view. Then move the eyepiece in or out till the cross wires are as sharply defined as possible. When satisfied with the definition remove the eye to rest it and then look again. The wires should still look

sharp without having to strain the eye in any way. If not, try a slight adjustment of the eyepiece and repeat the experiment till the definition is perfect at the first glance. It is then a good plan to mark the position of the eyepiece by scratching a fine line on the tube against the end of the socket using a sharp knife or needle point. **Parallax—** *(contd.)*.

Then when focussing any near or distant object, *keep the attention fixed on the wires* and move the object glass to and fro till the distant object is quite sharp and does not move relatively to the wires when the eye is moved laterally. This result must be attained *by moving the object glass only* and not by attempting to fiddle with the eyepiece for this has already been adjusted and is known to be correct. It may be noted that different observers will usually need different adjustments of the eyepiece, but that the individual adjustment, when once found does not vary appreciably from day to day.

Unless the above points are attended to before commencing work, the results are certain to be very indifferent.

Angular measures. Method of observing.

4. (*a*) Having carefully levelled and centred the theodolite over the mark, the back station is intersected using either tangent screw after both plates have been clamped, particular care being taken to clamp the lower plate firmly: the horizontal reading is then taken and entered in the field book.

(*b*) The upper plate is then released and the forward station intersected using the upper tangent screw, and the horizontal reading is again recorded.

(*c*) Keeping the upper plate clamped, the lower plate is released and the instrument turned again to the back station, intersecting by the lower tangent screw. The reading of the arc should obviously not be altered by so doing; nevertheless the arc should be read again to see that no change has taken place.

(*d*) Next release the upper plate, and, having again intersected the forward station with the upper tangent screw, record the third reading.

(*e*) Then by subtracting the first from the second reading, we get one measure of that angle which lies to the left of the observer when facing his forward station, and similarly, taking the second from the third, we get another independent measure of the same angle, from a different portion of the arc. These angles are taken out immediately afterrecor ding thethird reading and entered on the right side of the field book: if they do not agree within 2′ of arc, a third independent measure is taken in a similar way, and entered above the others.

Angular measures. Method of observing—(*contd.*).

This accordance is a test of the intersection and reading of the theodolite. Error due to incorrect centering of the theodolite over the station peg, and observations made to a sloping staff are quite independent, and are dealt with below.

Remarks on angular measures.

5. It will suffice to read angles on one vernier only provided the same vernier is always used.

The back station must be intersected first, otherwise the supplement of the angle, described in paragraph 4 (*e*) above, will be measured, and this being unnoted and unknown to the computor, the traverse will not prove.

The time occupied in taking the second measure is very small as compared with the total time required to centre and level the instrument, and if the above method be strictly carried out, it is quite impossible for any gross error to creep into the angular measurement.

The instrument must be carefully centred over the station mark. Also the staff must be accurately placed over the forward pillar or peg. For very short distances it is a good plan to observe to a chain pin held vertically on the pillar.

An error of 1 inch in the centring of the theodolite or the intersection of the mark will produce an angular error of nearly 5′ at a distance of one chain, and the angular error increases as the distance diminishes: consequently the smaller the distance between stations, the greater is the necessity for care both in centring the instrument and staff, and also in making the intersection of the latter. When therefore the distant peg cannot be seen, the staff must be held in a vertical position. The observer must also see, by bringing the vertical cross wire of his telescope on to the staff, and swinging the telescope about the transit axis, that the staff is truly vertical, *i.e.*, that as seen in the telescope it coincides with and remains on the vertical cross wire. If it does not he must signal to the men holding it to move the staff in the appropriate direction, until it is correct. This done he must carefully set the cross wire to intersect the lowest visible portion of the staff.

Linear measures.

6. As the officer who is making the traverse is not likely to be in regular pratice at such work it will be best for him to confine his attention to the angular measurements and leave the chain measurements to a subordinate. He will however book them and check them in every case as described below.

Distances between stations are measured either directly with a chain or indirectly by means of a subsidiary triangle or a subtense bar. The latter method is far the best in really steep broken ground, but no description of it will be given here. If work has to be done in such localities, it will be best to obtain the pamphlet

"Traversing and its computation" published by the Survey of India, Wood Street, Calcutta, and read up the subject. Linear measures—(*contd.*).

Chain measurements

Each traverser should be supplied with one chain 100 feet long, one chain 66 feet long, and one steel tape 100 feet long. The latter is to be used as the standard for checking the chains and for this purpose only. Before starting work check both chains by means of the steel tape and reduce them to the correct length within half an inch by removing as many short links as may be necessary, which is easily done with a pair of strong pliers. Also see that the 10-link metal tabs are in their proper places or terminal measures will be incorrect. All chain men should be given strict orders that the marking pins must be put into the ground truly vertically. Much accuracy is lost by pins being put in on the slant. Measurements also should be made to a point of the pin near to the surface of the ground.

Two men are required for each chain and the long chain should precede the shorter because it will go faster. The subordinate will accompany the short chain, keeping his eye on the line taken by the long chain to prevent deviation. Intermediate measures and offsets are seldom required but see specimen Field Book at paragraph 8 for an example of the former.

On arriving at the forward station the traverser first records the total distance in terms of the short chain and on the line above, the distance given by the men with the long chain. Before doing anything else he reduces the measurements obtained in feet by the long chain to links by the rule of thumb method shown below :—

First example—

12·72=recorded long chain measure.
 6·36
——
19·08 (obtained by adding half).
 ·19 (Add the first two figures of the third line removed two places to the right).
——
19·27 reduced measure in short chain.

Second example—

3·41=recorded long chain measure.
1·705
——
5·115
 ·051
——
5·166=reduced measure in short chains.

Chain measurements—(*contd.*).

Assuming the chains and chaining free from error, this result must correspond exactly with the recorded short chain measure. In practice, however, the two measures rarely agree exactly, but provided the difference does not exceed one link for every five short chains, the measures may be accepted. Thus in a line of 19·27 short chains, the long chain measurement would be accepted as correct if, when reduced, it lies between 19·23 and 19·31. Whenever a larger difference occurs, the whole line must at once be remeasured by both chain squads, the new measures being recorded above the old ones, which are then crossed out and initialled (see Z3 in specimen Field Book at paragraph 8).

At first, no doubt, time will be lost in remeasuring lines, but after sending the men back a few times, they will become more careful, and the work will proceed as rapidly as if measured by a single chain only. This method of chaining requires more men than for a single chain and is therefore more expensive, but if conscientiously carried out gross errors are almost impossible.

Reducing lengths for slope of ground.

On sloping ground all chain measurements have to be reduced to their horizontal equivalents. The correction applied depends on the vertical angle recorded. This angle, as will be seen from the following table, is only required to the nearest half degree and can be obtained either with the theodolite or more simply by using a hand clinometer. The observation must of course be taken to a point at about the same distance above the ground as the telescope of the theodolite.

The correction to observed length of one chain is—100 $(1 - \cos\theta)$ links, θ being the slope of the ground. It is always negative and is given in the following table :—

Correction to 1 chain.

Slope.	Links.	Slope.	Links.	Slope.	Links.	Slope.	Links.
		4° 30′	0·31	9′ 0′	1·23	13′ 30′	2·76
0° 30′	0·00	5° 0′	0·38	9° 30′	1·37	14° 0′	2·97
1° 0′	0·02	5° 30′	0·46	10° 0′	1·52	14° 30′	3·19
1° 30′	0·03	6° 0′	0·55	10° 30′	1·67	15° 0′	3·41
2° 0′	0·06	6° 30′	0·64	11° 0′	1·84	15° 30′	3·64
2° 30′	0·10	7° 0′	0·75	11° 30′	2·01	16° 0′	3·87
3° 0′	0·14	7° 30′	0·86	12° 0′	2·19	16° 30′	4·12
3° 30′	0·19	8° 0′	0·97	12° 30′	2·37	17° 0′	4·37
4° 0′	0·24	8° 30′	1·10	13° 0′	2·56	17° 30′	4·63

FLY LEAF.

Description or number of traverse.

Zone boundary No. 1.

Field Book checked by A. Smith, Lt. R.E., 20·1·12

Chain Measurements at begining of each day's work.

Date.	66' chain.	100' chain	Remarks
15·1·1912	66'·1½"	100'·2"	Both chains corrected.
16·1·1912	66'·0½"	100'·0½"	

Starting Point .... *C.B.P. No. 15.*

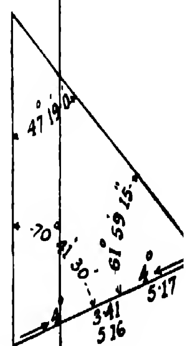
Closing Point .... *C.B.P. No. 94.*

Commenced .... *15·1·1912.*

Finished .... *16·1·1912.*

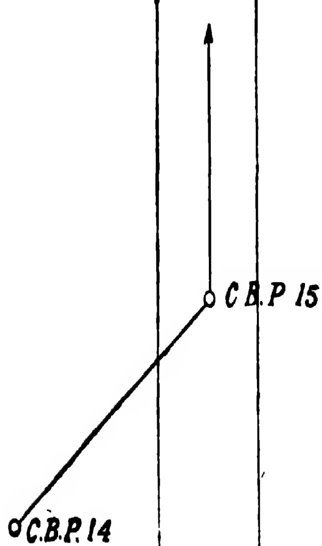
Observed by .... *B. Jones S.D.O.*

	Z1⊙	
	259·51·30	
	197·52·0	61·59·30
Angle at A.	135·53·0	61·59·0



3·41		
1·705		
5·115		
51		
5·116	135·50·30	
	65·08·30	70·42·0 A
	271·40·30	153·28·0
	200·59·30	70·41·0 A
	47·31·30	153·28·0

	⊙1	Peg.
4·43	4·43	= 6·71
2·215	6·71	
6·645		
66		
6·711		
	265·0·30	
	145·18·30	119·42·0
	25 38·0	119·40·30



When the slope is less than 4 degrees it is hardly necessary to make any correction.

Reducing lengths for slope of ground—(*contd.*).

Measuring by triangle.

7. Occasionally an obstacle will prevent any kind of chaining between stations, and the traverser, if not provided with a subtense bar, may avoid the difficulty by laying out a base of suitable length on any level or evenly sloping piece of ground. One end of the base will coincide with the traverse station and its direction should be, as nearly as possible, perpendicular to the line whose measure is required (see specimen Field Book at para. 8, ⨀ 1 to ⨀ Z1).

In addition to making accurate measurements of the base itself, a satisfactory result can only be obtained if the following conditions are satisfied :—

(*a*) All three angles of the triangle must be carefully measured, reading all verniers if any angle is less than 10°.
(*b*) The sum of the angles at each end of the base must not exceed 170°.
(*c*) The vertical angles along each side of the triangle must be recorded to the nearest half degree if the slope exceeds 4°.

Recording observations in the Field Book.

8. A specimen field book on a reduced scale is shown facing this page, from which the method of making entries may be seen. The fly leaf should be entered up as shown, as a record that the chains were corrected, when necessary, before use each day.

Between peg I and Z1 is an example of how to enter a triangle when direct measurement is impracticable. It will be noticed that the base 1 to A has a slope of 4° so that the recorded measures will have to be reduced to the horizontal by the table in paragraph 7. Also that as none of the angles are less than 10° only one vernier is read.

From Z1 to peg 2 is an example of chaining over broken ground with the aid of a hand clinometer. Pillar Z2 being inaccessible, a peg had to be used as described in paragraph 21.

In measuring from peg 2 to Z3 it will be seen that one short chain was dropped, the mistake being detected by comparing the long and short chain results on the spot.

Computations.

9. To compute a traverse it is necessary to know the horizontal lengths of each side and their bearings from true North. The traverse may be computed either in feet or links. In either case the mean of the measures given by the two chains may be used, or else the measures given by the long chain only which should perhaps be the more accurate of the two.

Computations—(*contd.*):

All Survey of India Cantonment maps are based on traverses which are worked out in chains and links (one chain =100 links= 66 feet). Work which is to be embodied on Survey of India plans should therefore be computed in the same manner and not in feet, so that the rectangular co-ordinates can be plotted direct on the map. In other cases it will generally be more convenient to work in feet.

Horizontal lengths of sides.

10. The distances as measured on the ground have to be corrected for (*a*) slope of ground and (*b*) error in length of chain. The first of these corrections is dealt with in paragraph 7 above. The second correction can be neglected provided the chain is kept corrected as explained in paragraph 7.

Bearings.

11. If the correct bearing of one line is known, the bearings of all other lines are readily obtained by applying the angles observed at each traverse station.

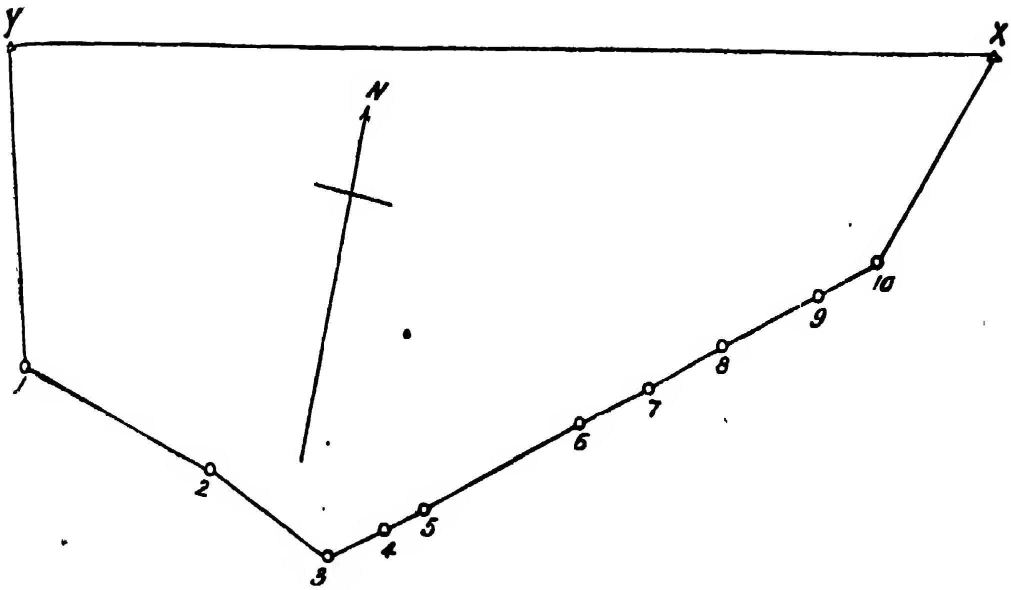
But it is not always easy to get a correct value for a bearing. It can of course be obtained by observing the azimuth between two stations and then applying a correction for the convergency between the meridians passing through the origin of the survey and the station of observation respectively. Excluding this method which cannot be dealt with in these notes, there are two alternatives. The first is applicable only in the case of maps which have been executed by the Survey of India. In such maps the rectangular co-ordinates of every Cantonment boundary pillar are known and the best plan is to write to the Superintendent, Trigonometrical Surveys, Dehra Dun, and ask him for the bearings and distances between the boundary pillars and their co-ordinates, if these are not already tabulated on one of the survey sheets. Given these data it is only necessary to include one or more of the known pillars in the traverse.

Figure 2 shows another case, in which stations 1 to 7 again represent the new traverse, whilst, A, B, X and Y are Cantonment boundary pillars whose co-ordinates and bearings have been obtained from the Survey of India. The traverse A 1 2 X is first run with the sole object of getting the positions of 1 and 2 and the bearing between them, whence the remainder of the new traverse can be readily computed.

Finding true bearing from magnetic bearing.

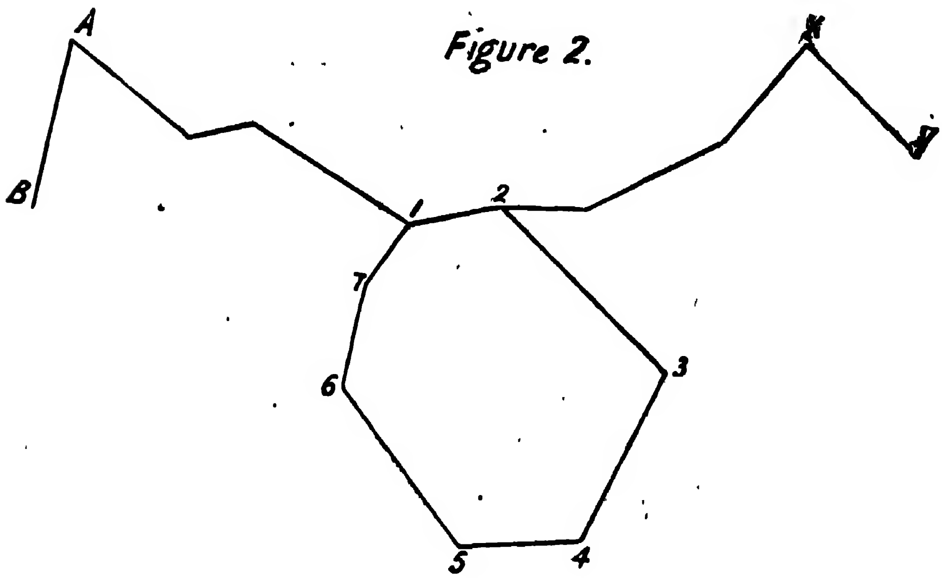
12. But if no data are obtainable from the Survey of India, a fairly accurate initial bearing can be got by finding the magnetic bearing of one of the lines and then applying the mean magnetic variation of the place in order to get the bearing from true North. The mean magnetic variation changes from year to year, but can always be obtained on application to the Superintendent, Trigonometrical Survey, Dehra Dun.

Figure 1.



The above figure represents a traverse including the points X and Y which are intervisible adjoining Cantonment boundary pillars. The co-ordinates of X or Y and the bearing between them having been obtained from the survey records it is obvious that the whole traverse can be computed without difficulty. In the above figure stations 3 to 10 may represent some of the pillars of a new zone boundary which has to be demarcated. The lines from X to 3 and Y to 10 are subsidiary lines which have to be run with the sole object of utilising the known data of the points X and Y without which it would not be possible to compute the traverse 3 to 10 and accurately locate it on the map.

Figure 2.



To get a good value of the magnetic bearing of the traverse line, the following precautions are necessary :— Method of finding Magnetic North.

(*a*) The magnetic needle supplied with the theodolite must be in good order.

(*b*) The station of observation must be away from large underground pipes, iron fences or other masses of metal which would vitiate the result.

The needle box having been securely clamped in position and the theodolite centred and levelled, the lower plate is securely clamped. The needle is then set free and the upper plate turned till it is swinging in the magnetic meridian. When the needle has almost steadied itself the box should be gently tapped with a pencil to overcome pivot friction.

When quite steady the North end of the needle is brought exactly opposite the index mark by clamping the upper plate and using the slow motion screw. One vernier is then read to the nearest minute and recorded. The needle is then disturbed and the South end is similarly dealt with, the reading of the same vernier being recorded. Several pairs of readings are thus obtained, the mean of which X gives the reading of magnetic North on the lower plate. Releasing the upper plate the distant station is then intersected and a single reading Y of the same vernier recorded. Then the difference between X and Y gives a value of the magnetic bearing of the line from the theodolite to the distant point. These observations should be repeated on several days and the mean of all the results used.

It may be noted that if consecutive readings of the same end of the needle differ by many minutes of arc, or if the results obtained on different days vary more than say 10′, it is certain that the needle is out of order either from lack of magnetism or from a blunted pivot. A defective needle should be sent at once for repair to the Mathematical Instrument Office, Wood Street, Calcutta, if it cannot be put right locally. With care and a good needle the bearing from true North can be obtained within a quarter of a degree or less, which may suffice in the case of work which is not to be entered on a Survey of India sheet.

13. The example worked out on p. 264 shows a convenient form for the computations and the various stages are explained in the following paragraphs. Before entering up the observed data, it is generally convenient to make a rough plot of the traverse by bearings and distances (see Figure 1 which is a rough plot of the computed traverse). Form of Computation General explanation.

It is convenient to enter all known bearings and co-ordinates and also the corrections in red ink, the observed data and calculated results being in black.

MILITARY WORKS SERVICES.

Name of place or Cantonment **Year 19**

Computation of Co-ordinates or Traverse Stations

TRAVERSE NO.

Point of departure **Closing Point**

Stations.	Theodolite Readings.		Correction	Bearing or Direction with respect to Meridian of Origin to nearest minute.		Distances.		DISTANCES ON THE — MERIDIAN. — North.			South			PERPENDICULAR. — East.			West.			MERIDIAN — Of each Station from the origin.		PERPENDICULAR. — Of each Station from the origin.		REMARKS.
	°	′		°	′	Chains	Links.	Chains.	Links.	Corrections.	Chains.	Links.	Corrections.	Chains.	Links.	Corrections	Chains.	Links.	Corrections.	Chains	Links.	Chains.	Links	
X Y	83	48	+	258	4	..		..	..	+			—			—			+	S1846	68	E 693	74	Bearing X to Y.
1	119	38	1	161	52	56	30				53	30	2	17	52	3				1900	16	711	23	
2	189	42	..	101	31	40	20				8	03		39	39	6				1908	19	750	56	
3	125	36	..	111	13	29	37				10	63		27	38	4				1918	82	777	90	
4	179	45	1	56	49	12	44	6	81					10	41	1				1912	01	788	50	
5	179	35		56	35	9	28	5	11					7	75	1				1906	90	796	04	
6	182	9	..	56	10	35	87	19	97	1				29	80	4				1886	92	825	80	
7	176	23	..	58	19	15	63	8	21					13	30	2				1878	71	839	08	
8	182	7	..	54	42	16	83	9	73					13	74	2				1868	98	852	80	
	148	16	1	56	49	21	46	11	75					17	96	3				1857	23	870	73	
X	52	58	..	25	6	58	65	53	11	3			..	24	88	3				1804	09	895	58	
Y	..	..	..	258	4	206	00		..		42	60	1				201	55	29	1846	68	693	74	
	1619 360	57 00						114	69	4	114 114	76 69	3	202 201	13 55	29	201	55	29					
	1979 1980	57 00	=22×90					Difference			=	7			58									
	Error	—3																						

The stations are entered consecutively in the first column commencing with those at each end of the side whose bearing is known, in this case X Y. On the line opposite to each station is entered the angle observed at that station and the distance to it from the previous station. The starting bearing X to Y is written opposite Y, so that when all bearings have been run down as explained below, we have opposite each station the bearing and distance *to* that station *from* its predecessor.

Form of Computation General explanation—(*contd.*).

Closed Circuit.

14. In the case of a closed circuit (Fig. 1) the angles to be entered in column 2 are the interior angles. As pointed out in para. 4(*e*) the angle observed at each station is the angle lying to the left of the observer when facing the forward station. Hence if the stations are traversed in an anti-clockwise direction, *i.e.*, as numbered in Fig. 1, the observed angles are the interior angles of the polygon and may be entered directly in the form. But if the work had been done in the opposite direction the supplement of each observed angle must be entered, *i.e.*, 360° minus the angle observed.

The sum of all the interior angles$=(2n\times 90°)-360°$, where n is the number of sides of the traverse. In practice the sum of the observed internal angles will be greater or less than the correct amount by a few minutes. This error must be distributed with its correct sign in the next column.

Distribution of angular error.

15. It is generally credited to stations having one or more very short legs for reasons given in para. 5—, but in careful work the error is always small and no greater correction than 1′ should be given at any station. Or the error may be distributed more or less symmetrically as in the example.

Open circuit.

16. In the case of a traverse which does not close itself (Fig. 2) the observed angles may be entered as booked.

Bearing in mind the situation of the observed angles with reference to an observer facing the forward station, it is easy to carry down the bearings from the given initial bearing to the given closing bearing. The difference between this given value and that derived from the traverse is the closing angular error which is distributed as above explained either symmetrically or along the shortest sides.

It may happen that the traverse closes on a point whose co-ordinates are known but that a closing bearing is not available. In this case the angular error cannot be determined and adjusted and the observed angles must be taken as correct, the whole of the errors being then distributed amongst the ordinates as explained in paragraph 18. But this should not be done if a closing bearing is available.

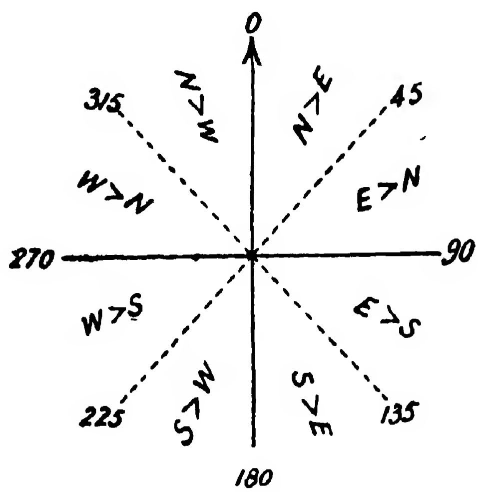
Computation of co-ordinates.

17. Having thus obtained the corrected bearings and horizontal distances, the co-ordinates of each station referred to the previous point as origin are found from the equations:

$$\left.\begin{array}{ll}\text{Meridian} & = L \cos B \\ \text{Perpendicular} & = L \sin B\end{array}\right\} \begin{array}{l}\text{Where } L = \text{Corrected distance} \\ \qquad B = \text{Bearing from N.}\end{array}$$

These quantities are required to the nearest link and are best worked by using tables of logarithmic* sines, cosines and numbers. Five place logarithms are used in the computations.

The bearing may be anything from 0 to 360, but in ordinary tables of log sines and cosines the values are given only for angles from 0 to 90. It will be convenient therefore to work with a diagram before one like this.



If the bearing is say 314° 27′ take out the log sine and cosine of 314° 27′—270°=44° 27′, and add the log distance to each. Take out the numbers whose logarithms are represented by each of the sums so obtained and these numbers will give the number of chains and links in the co-ordinates. In the half quadrant between 270° and 315° it is clear that the Westing must be greater than the Northing, so that the bigger of the resulting co-ordinates must be the Westing in this case.

Similarly for a bearing of say 265° 17′ take out the log sine and log cos of 85° 17′ (*i.e.*, 265° 17′—180°) and obtain the co-ordinates as before. In this half quadrant the Westing is always bigger than the Southing and this consideration shows which co-ordinate is which without further thought.

* Chambers' Tables are suitable. They are obtainable on indent from the Mathematical Instrument Office, Wood Street, Calcutta.

The following is an example showing how best to arrange the computations of the co-ordinates:— *Computation of co-ordinates—(contd.).*

Traverse station	Distance Bearing.	
		log co-ord.=0·13636=log of 1·3
	1·37 (chains)	
		log sine 87·40=9·99964
1.	357° 40′	log 1·37=0·13672
		log cos 87·40=8·60973
		log co-ord =2·74645=log of 0·06

In the half quadrant containing 357° 40′, the Northing must be greater than the Westing. Hence the co-ordinates are 1·37 N. and 0·06 W.

When working out a number of co-ordinates it will be found convenient to take out all the log numbers first; then take out all log sines and cosines, add up the two upper and two lower lines and finally take out all corresponding numbers. The co-ordinates are then written in their proper columns in the traverse form under N. S. E or W by inspection of the diagram as above explained wihout any reference to whether the sine or cosine has been used in the calculation. This method is quicker and less liable to computation errors than that of completing the computation of each station before going on to the next.

18. In the case of a closed traverse, the sum of the Northings should equal the sum of the Southings and similarly for the Eastings and Westings. The difference between corresponding sums represents the error which has to be distributed proportionately to the length of the ordinates as shown in the example. *Distribution of linear errors.*

In the case of a traverse starting from and closing on different known points (as in Fig. 2) the difference between the sum of the Northings and Southings of the co-ordinates should equal the difference between the N or S. co-ordinates of the known starting and closing points. If not the error is distributed proportionately and the Eastings and Westings are then similarly dealt with.

The final step is to deduce the co-ordinates of each point with reference to the common origin, the method of doing which is apparent from the examples given and needs no explanation.

19. If the work is to be on to a Survey of India map the best plan is to draw pencil squares accurately across the sheet from the co-ordinate lines which are always printed on the marginal sheets. As there are 80 chains in a mile, on the usual scales of 12″ and 16″ to a mile, one chain is represented by 3/20″ and 1/5″ respectively and it is an easy matter to construct paper scales accordingly. By *Plotting traverse.*

Plotting the traverse.

plotting directly on the map, errors due to the distortion of the paper are minimised and a better result is obtained than can be got by plotting on tracing paper and then pricking through. After plotting all points by co-ordinates, the result should be checked by the distances entered in the Traverse form. If the points fall very close together, extreme accuracy in plotting is essential, as otherwise a very slight error will so displace the point as to make its bearing from its neighbours differ considerably from what it should be as recorded in the form.

Selecting traverse stations.

20. The object of the traverse being to obtain the co-ordinates of certain boundary pillars with the bearings and distances between them, the theodolite should always be centred over the pillar, with or without the use of the tripod stand.

In starting a traverse from old pillars whose co-ordinates are known, it is essential that this shall be done in the case of the first pillar observed at, even if a temporary platform has to be erected for the purpose.

Inaccessible pillars.

21. But it not infrequently happens that a pillar is embeded in or lies so close to a wall or fence that observations cannot be taken over it. In such a case a peg may be driven close by and when taking the angles from the back station, readings will be taken to the pillar as well as to the forward station. The distance from the peg to the pillar is also measured and recorded. From the bearing and distance thus obtained it is easy to calculate the co-ordinates of the pillar from that of the peg station.

Bearings and distances from co-ordinates.

22. As however the distances and bearings between pillars are required for publication in the schedule of the boundary it will, in such cases, be necessary to compute these quantities from the co-ordinates.

If A and C are two points whose co-ordinates are N. E. N^1 E^1 respectively, the bearing of C from A is the angle whose tangent is $\frac{E^1-E}{N^1-N}$. Here E^1-E, N^1-N may either or both be positive or negative. Let θ be the angle such that $\tan\theta=\frac{E^1-E}{N^1-N}$ without regard to sign.

If E^1-E is	+	and N^1-N is	+	the bearing is . .	θ
,,	+	,,	$-$	,, . .	$180-\theta$
,,	$-$	,,	$-$	,, . .	$180+\theta$
,,	$-$	,,	+	,, . .	$360-\theta$

The distance $AC=\sqrt{(E^1-E)^2+(N^1-N)^2}$.

Example :— Bearings and distances from co-ordinates—(*contd.*)

A co-ordinates 181·71 N 21·35 E.

C ,, 15·23 S(N^1) 111·79 W (E^1)

Here E^1 E=—111·79— 21·35=—133·14.

N^1—N=—15·23—181·71=—196·94.

$$\tan\theta=\frac{-133\cdot14}{-196\cdot94}\quad \begin{array}{l}\log 133\cdot14=2\cdot12431.\\ \log 196\cdot94=2\cdot29433\end{array}$$

$$\log\tan\theta=9\cdot82998$$

$$\text{and}\quad \theta=34^\circ\ 4'$$

Hence the bearing A to C=180°+34° 4′

=214° 4′

Distance A C=$\sqrt{133\cdot14^2+196\cdot94^2}$

= 237·72 chains=156·9 feet.

This latter computation is best done from tables of Quarter Squares. (Chambers' Tables.)

ADJUSTMENT OF LEVELS.

1. The following notes apply to the Cooke's Reversible and Y pattern levels, which are the types most commonly used. Adjustments should be made in the following order :— General

(*i*) Eliminate parallax, *i.e.*, make the focus of the eyepiece and the image formed by the object glass coincide on the plane of the cross wires (see page 258).

(*ii*) Adjust for collimation, *i.e.*, axis of the socket or bottom of Y's parallel to the line of sight.

(*iii*) Make these lines parallel to the horizontal plate, *i.e.*, perpendicular to the axis of rotation.

(*iv*) Make line of axis of bubble parallel to all three.

The line of sight is a line joining the optical centre of the object glass with the intersection of the cross wires.

2. Having set up the level on its stand, turn the telescope over a foot screw and direct it on a clearly defined object so as to intersect it with the cross wires. Then clamp the instrument, withdraw the fixing screw (in the case of the Cooke's level) and turn the telescope half way round in its socket, so that the cross wire is again horizontal but reversed. If the cross wire does not now intersect the object, the error must be corrected half by means of the foot screw and half by the diaphragm screws, by means of which the cross wire is adjusted, the operations being repeated till the adjustment Collimation

Collimation —(*contd.*). is perfect. In the case of the Y level, the telescope is turned in the Y's, and the error adjusted in the same manner.

3. To make the line of sight parallel to the horizontal plate intersect an object with the horizontal cross wire as before. Carefully reverse the telescope end for end in the socket or Y 's, unclamp the horizontal plate, and turn the telescope through 180°. If the cross wire does not again intersect the object, the error is correctd half by means of the foot screw and half by means of the screws controlling one ring of the socket in the case of the Cooke's level, or one of the Y's in the case of the Y pattern. As a check reverse the telescope again and take another reading, and continue as before until the error is eliminated.

The instrument need not be level when making either of the above adjustments.

Axis of bubble. 4. Adjustment of axis of bubble :—To level the instrument place the telescope over one foot screw, and turn the latter until the bubble is in the centre of its run. Turn the telescope through 90° so that it is over the other two foot screws, and turn both screws, in such a manner that both thumbs move inwards or both outwards, so as to bring the bubble to the centre of its run. Read one end of the bubble (say the object glass end) turn the telescope through 180°, and read *the same end* of the bubble as before. Adjust the foot screws until this same end of the bubble reads the mean of the above two readings say 7. Turn the telescope over the first foot screw again and adjust it till the same end reads 7. Repeat this process till the object glass end of the bubble reads the same for any position of the telescope.

5. The instrument is then truly level, but the bubble may not be exactly in the centre of its run. If the displacement from the central position is considerable, the whole bubble is moved by means of the antagonistic capstan headed screws at one end of it, care being taken to release one screw before tightening up the other.

It is a very troublesome matter to get the bubble exactly central without disturbing the general level of the instrument, and, provided it is within one or two divisions of the correct position, no attempt should be made to improve matters. Even if the adjustment is made perfect it will seldom remain so for long.

6. But there is no difficulty in levelling an instrument the bubble of which is slightly out of adjustment, if the procedure described in the first part of this paragraph is followed.

7. Unless a level has been tested and is known to be in perfect adjustment, the only way to get good results is to make the front and back shots of equal length by measurement. This is advisable in any case where great accuracy is desired, as by so doing the

same focussing of the telescope will serve for both shots, thereby eliminating a source of error over which there is no control. Axis of bubble—(*contd.*).

LIGHTNING CONDUCTORS.

General.

A lightning flash from a cloud to earth occurs as the result of the electrical tension produced between a cloud heavily charged with electricity and the earth beneath it. The flash tends to pass to the nearest point, *i.e.*, to anything projecting from the earth such as buildings, trees, etc. Several successive flashes may occur from the same cloud.

2. A lightning conductor consists of a metal rod, provided with one or more sharp points, in metallic connection with the earth, fixed on a salient feature of a structure to protect it from damage by lightning. It acts in two ways :—

(1) The points dissipate the charge and so tend to relieve the tension. A flash may thus be averted, or should it occur, its force will probably be greatly reduced.

(2) If a flash takes place the conductor provides a better path to earth than that through the buildings and so conducts it safely to earth.

In certain circumstances a flash may occur suddenly before the points have time to act; in such cases the conductor acts only as in (2) above.

3. To fulfil these objects the following conditions are necessary :—

(*a*) The conductor must provide an efficient metallic connection from the rod to earth, which shall not merely have a low electrical resistance, but must follow as direct a route as practicable without sharp angles or upward bends.

(*b*) All parts of the conductor, including the rod and joints, must be of sufficient size not to be melted or damaged by the flash.

(*c*) The rod should have one or more sharp points.

(*d*) The connection to earth must be the best obtainable in each case having regard to the nature of the soil.

In order to comply with (*b*) and (*c*) the rods on main features are usually fitted with several sharp tapered points, the rod itself being of stouter section with a blunt point.

4. Lightning conductors should be provided for all magazines, whether above or below ground, and important buildings, such as churches, etc. Cartridge and shell stores and expense magazines need not be fitted with lightning conductors, except in cases where

General (*contd.*).

they occupy very exposed sites, or have much metal connected with them.

5. Barrack buildings in exposed position should be provided with conductors when experience has shown that the locality is liable to lightning. In such cases the use of metal rods or ropes for punkah suspensions should be avoided.

6. There is no reliable rule concerning the area of protection given by a conductor of given height. Any object to be thoroughly protected from lightning must be furnished as described with proper conductors. It is considered that a number of small conductors well connected at top and bottom, provide a better protection to a building, than an equal amount of metal, in large conductors, disposed at greater intervals.

Arrangement of conductors.

7. The angles and prominent portions of a building being most liable to be struck, the lightning rods should be fixed on gable ends, chimneys, turrets, etc., and they should all be connected together by continuous conductors along the ridges.

8. The main lightning rods on the main features of the building should be spaced at intervals not exceeding 50 feet, so that no point on the building is more than 25 feet horizontally distant from such a rod. Each of these main rods should be connected by a vertical conductor to earth by the shortest practicable path outside the building. Where there is any choice, it is desirable to carry the conductor down the side of the building which is most exposed to rain. Subsidiary conductors from minor features and as a general rule, all metals on the roof, such as chimney cowls, flashing, ridging, ventilators, gutters and rain water pipes, should be connected to the system by the shortest route.

9. In all situations, where more than one vertical conductor is used, all of them, in addition to being connected at the top, should also be connected by a horizontal conductor near the ground line. This lower horizontal conductor should be carefully connected to the earth in such a way that the earth connections form direct continuations of the vertical conductors. All junctions in the lower horizontal conductor should be above ground both to admit of inspection and to prevent local galvanic action; it is desirable that those for the earth connections should be made by screw clamps to facilitate disconnection for testing.

10. The "lightning rods or terminals should project about 3 feet above that portion of the building to which they are attached and should preferably be of the same metal as the conductors. At the main features a four point rod should be provided, single point rods being used for subsidiary features. Where copper or iron wire rope conductors are used and where appearance is not of great moment, the rod or terminal may consist of the rope conductor

itself, the strands of the rope being opened out to form the points. The oxidation of the points does not impair the value of the rod.

Arrangement of conductors— (contd.).

11. When a tall chimney or other inaccessible erection has to be protected from lightning the best plan is to carry a continuous conductor up one side and down the other, to use two earth connections, and to employ a connecting conductor just above the ground line and also one round the outside of the top of the cap and a few inches below it with terminals projecting 1 foot above the top of the shaft at intervals of 3 or 4 feet all round. A similar arrangement is suitable for church spires.

12. In barracks with iron roofs it is sufficient to connect the roof covering to earth by means of iron conductors rivetted to it at the eaves at each corner of the building. Where masonry chimneys exist, a conductor, which may consist of a strip of sheet iron 6 inches wide, must pass over the top of the chimney and be rivetted and soldered to the roof covering on each side of it. Iron verandah roofs must be connected with iron main roofs.

13. Conductors should not be insulated from the buildings to which they are attached; they should be fixed to the walls with holdfasts of the same metal as the conductors themselves and the fixing arrangements should be such as to allow free expansion and contraction, which with copper conductors may amount to about 1 inch in 60 feet.

14. In erecting conductors unnecessary bends are to be avoided; all bends should be gradual; sharp re-entering angles are not admissible. In order to ensure this, the conductors may be led with an easy curve round large projections by means of holdfasts supporting the conductor a few inches away from the wall. When this is impracticable conductors should be taken through the projections.

15. As a general rule a conductor should be connected to all metals which may be within 4 feet of its course on the outside of a building; this includes such apparently insignificant metals as cramps and ventilators set in walls. A conductor should be either connected to, or kept as far away as possible from, iron girders or other masses of metal inside a building. Conductors, including any metals connected to them, which thus become part of the conductor system, should not be within 5 feet of gas pipes, internal or external electric wiring, or water pipes, except as provided in paragraph 22. It is advisable to connect church bells and turret clocks with the conductors.

Materials.

16. The conductors may be of iron or copper, whichever is most convenient in each case, but they should be of the same material throughout. The conductivity of the copper used is absolutely unimportant, except that high conductivity increases the surges

Materials—(*contd.*). and side flashes and therefore is positively objectionable. For this reason iron is more suitable, and where appearance and rust are not of much importance, iron conductors should always be used from motives of economy.

17. Solid rods, tubes, strips, and wire ropes of the same sectional area of metal, either of iron or copper, are considered to possess practically the same efficiency as lightning conductors. Conductors in the form of tape, rope or wire have the advantage of ease of fixing and also of requiring fewer joints.

18. The following may be taken to be the minimum sizes of conductors suitable for ordinary buildings where there are usually two or more conductors interconnected: copper or galvanised soft iron wire rope of $\frac{3}{8}$ inch diameter the rope to consist of stout wires, no individual wire being less than No. 12 S. W. G.; copper or iron rod $\frac{5}{16}$ inch diameter (say No. 0. S. W. G.) ; copper tape $\frac{3}{4}$ inch $\times$ $\frac{1}{8}$ inch.

19. For isolated or very long conductors, such as those on church spires or tall chimneys, a rather larger section should be used, *e.g.*, $\frac{1}{2}$ inch diameter copper or iron wire rope; copper tape 1 inch by $\frac{1}{8}$ inch; copper or iron rod $\frac{3}{8}$ to $\frac{1}{2}$ inch diameter. When, however, iron wire ropes are used in these or other inaccessible places, it is desirable to use a still larger diameter on account of the difficulty and expense of replacing them when rusted. Subsidiary conductors for connecting metal ridging, etc., may with advantage be of iron andof a smaller gauge, such as No. 5 S. W. G. galvanised iron wire.

Joints. 20. Metallic continuity should be ensured at the joints of all conductors. The joints should preferably be rivetted, screwed, spliced or otherwise mechanically joined. They may also be brazed, welded or soldered, but no reliance should be placed on a soldered joint without mechanical connection in addition as the solder is seldom sweated through the joint and often consists of an imperfectly adhering mass of metal hiding badly fitting and dirty surfaces. For these reasons it is considered preferable to ensure good metallic contact by mechanical means and to exclude damp from the joint by paint or otherwise. In rivetting tapes five rivets should be used and the holes should be bored, not punched. The sharp edges being removed and the surfaces brightened with emery, the joint should be brought together with a hollow punch before rivetting. When solder is used it should consist of equal parts of tin and lead for copper conductors, and for iron conductors molten zinc should be used. There should be no joints underground, but, if unavoidable, such joints should be covered with tarred tape. The joints should each possess a surface area equal to at least six times the sectional area of the conductor.

21. Where tape is used the connection between the lightning rod and the conductor is made by means of a slotted clamp similar in design to those employed for test or other joints. The lightning rod terminates at its lower extremity in a bolt, which is screwed into the clamp, thereby making firm contact with one or more tapes inside it, or the rod may be screwed into a metal support, extensions of which are formed into one or more clamps for the attachment of the tapes. This joint admits of visual inspection.

22. The earth connections should each have at least 18 square feet of external surface and may consist of copper plates 3′ by 3′ by not less than $\frac{1}{16}''$ thick, or galvanised iron plates of the same dimensions but $\frac{1}{8}''$ to $\frac{1}{4}''$ thick, well rivetted to the ends of the conductors ; or the earth may be formed by coiling one end of the conductor spirally on a wooden frame about 4 feet diameter and 4 feet wide, the turns being 3 to 6 inches apart. 100 to 200 feet of conductor, depending on its size, are required for this form of earth which obviates the necessity for any underground joint. Iron water mains form good earth connections and may be used for earths, the conductor being secured to the pipe, at or below the ground level by clamps or solder, or preferably by both methods. Soft metal pipes and gas pipes must not be used for earths : and should be kept as far away from conductors as possible : if, however, their proximity to a conductor underground is unavoidable, they should be connected to it. Earths.

23. Where the level of the water or permanently wet soil lies within a few feet of the surface, the earth plate or coil, as described above, should be buried in water or wet soil 15 to 25 feet from the building. Where, however, the permanent water level is deep and iron water mains are not available, a deep earth must be provided. This may be done by sinking the earth plate or coil at the bottom of a well which should not be less than 3 feet diameter and should be carried down several feet below the water level in the driest season. The lower portion of the well should be built without mortar. Copper earths should not be used in wells which supply drinking water. The conductors leading to the earths should be laid in trenches and surrounded by a few inches of coke or ashes.

24. When neither a well nor iron water mains are available for a deep earth the earth plate or coil should be buried in a mass of coke at the bottom of a pit, which should be sunk down to the dampest soil available, at a distance of about 30′ from the building. In extremely dry or rock situations the best plan is to bury several hundredweights of scrap iron round the coke, and carry a pipe up from the centre of the whole mass to the surface of the ground. Whenever practicable surface drainage and roof down

pipes should be arranged to discharge into the pit, and during the dry season water should be poured down the pipe.

Earts—(*contd.*) 25. Where deep earths are used, it is necessary, in important cases, to provide shallow earths in addition. The reason for this is that after a long period of dry weather the induced earth charge may be collected on a damp substratum, while after rain it may be on the surface. These shallow earths may consist of trenches, from 1 foot deep in clay to 2 feet deep in sand and shingle, leading away from the building. The trenches should be from 25 feet long in ordinary soil to 50 feet long in dry soil. The conductor should be laid along the bottom and through the whole length of the trench. A few inches of powdered coke or ashes should be spread above and below the conductor and the trench filled in with light soil. Wherever coke is specified in the preceding paragraphs, clean smith's ashes or charcoal may also be used.

26. Structures provided with lightning conductors should have as a rule, at least two separate earths, in addition to one or two shallow earths, which may be necessary in cases where deep earths are used. The conductors leading to the earths should be connected at the base of the structure above the ground line (*vide* paragraph 9).

In the case of buildings having 3 or 4 conductors, and where deep earths are necessary, the conductors at each end of the building should as a rule, be connected to deep earths and the intermediate conductors to shallow earth. Where the depth is considerable, 2 or more conductors may be connected to the same " earth "; in such cases the size of the earths should be made proportionately larger.

Testing. 27. Conductors should be tested immediately after erection and once a year at the end of the dry hot weather. This will be carried out by the garrison Engineer, or competent Subordinates, in the manner described in the " Code of Instructions for the Guidance of Public Works Officers in the Erection and testing of lightning Conductors," 1904, published by the Government of India, but visual inspection as to the mechanical and electrical conditions of the conductors above ground is to be chiefly relied upon, and electrical tests for the condition of the earths.

28. A record of such tests should be kept up in a book in each A. C. R. E.'s office, which should contain a description and plan of all important conductors in the district. This record should be a tabular statement showing (*a*) state of soil when inspected; (*b*) date of inspection; (*c*) lightning rods, state of points and connection; (*d*) conductors, and condition; (*e*) earths, condition and amount of resistance in ohms at each test.

Ferrotype Printing.

1. Paper for ferrotype printing can be obtained ready sensitised but it is often an advantage to prepare the paper as required. Prepare the following solutions:— Sensitising the paper.

(*i*) Citrate of iron and ammonia . . .	100 grains.
Distilled or rain water	1 oz.
(*ii*) Ferric Cyanide of Potassium (Redprussate of potash)	70 grains.
Distilled or rain water	1 oz.

Mix equal parts of the two solutions in a dark room immediately before use, and coat the paper with a sponge or cloth. The coating should be done twice cross-ways, taking care that no streaks are visible. The paper should be pinned to a drawing board during the operation and afterwards hung up in the dark to dry.

2. The exposure will vary according to light: it will be about 5 minutes in a clear sun, and more—up to 30 minutes—in cloudy weather. Exposure.

3. After exposure take out the print in a subdued light and wash it for about 5 minutes in at least two changes of cold water, until the whites in it are clear: then hang up to dry.

4. If the blue colour is faint and appears to wash out, it is a sign of too little printing. If the whites are not clear, the prints are overprinted, or the sensitised paper has been kept too long and has gone bad.

5. To obtain blue lines on a white ground a paper negative must first be prepared: this can be done as follows:— Paper negative method.

Make a tracing on bank post paper in common bazar writing ink, mixed with a little water until it is quite smooth and will just work freely in a pen.

The lines should be drawn fairly firm and black. Thoroughly mix a small quantity of lamp black and linseed oil, the amount depending on the size of the tracing and add about 15 drops of gold size. A fresh mixture must be made for each time of using.

6. Work the greasy mixture up with the edge of a velvet covered scraper, and coat the face of the tracing all over with it. The paper should be coated as evenly as possible by parallel strokes, no clots of ink being allowed on it, and it should appear almost perfectly opaque when viewed by transmitted light. Great care should be taken to keep the back clean. Now without delay, immerse the tracing in a large basin of cold water, and soak for a few minutes. It should then be drawn out and placed on a clean surface face upwards, and the face gently washed with water, using a camel hair brush on it lightly and plenty of water. If properly done, all the traced lines will clear out, leaving the design in white lines on

an opaque ground. If the brush is used too heavily, it will lighten the ground too much. The ink should dry hard in 24 hours.

7. Should there be much difficulty in clearing the lines, it is generally a sign that the greasy ink is too thick or that too much gold size has been added, it should therefore be thinned with a few drops of linseed oil before attempting another negative.

8. The ferrotype prints should then be printed from the negtives, as previously described.

9. Various methods of obtaining prints with dark lines on a white ground are described in the Roorkee treatise on Drawing, section XIII.

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CALCUTTA
SUPERINTENDENT GOVERNMENT PRINTING, INDIA
8, HASTINGS STREET

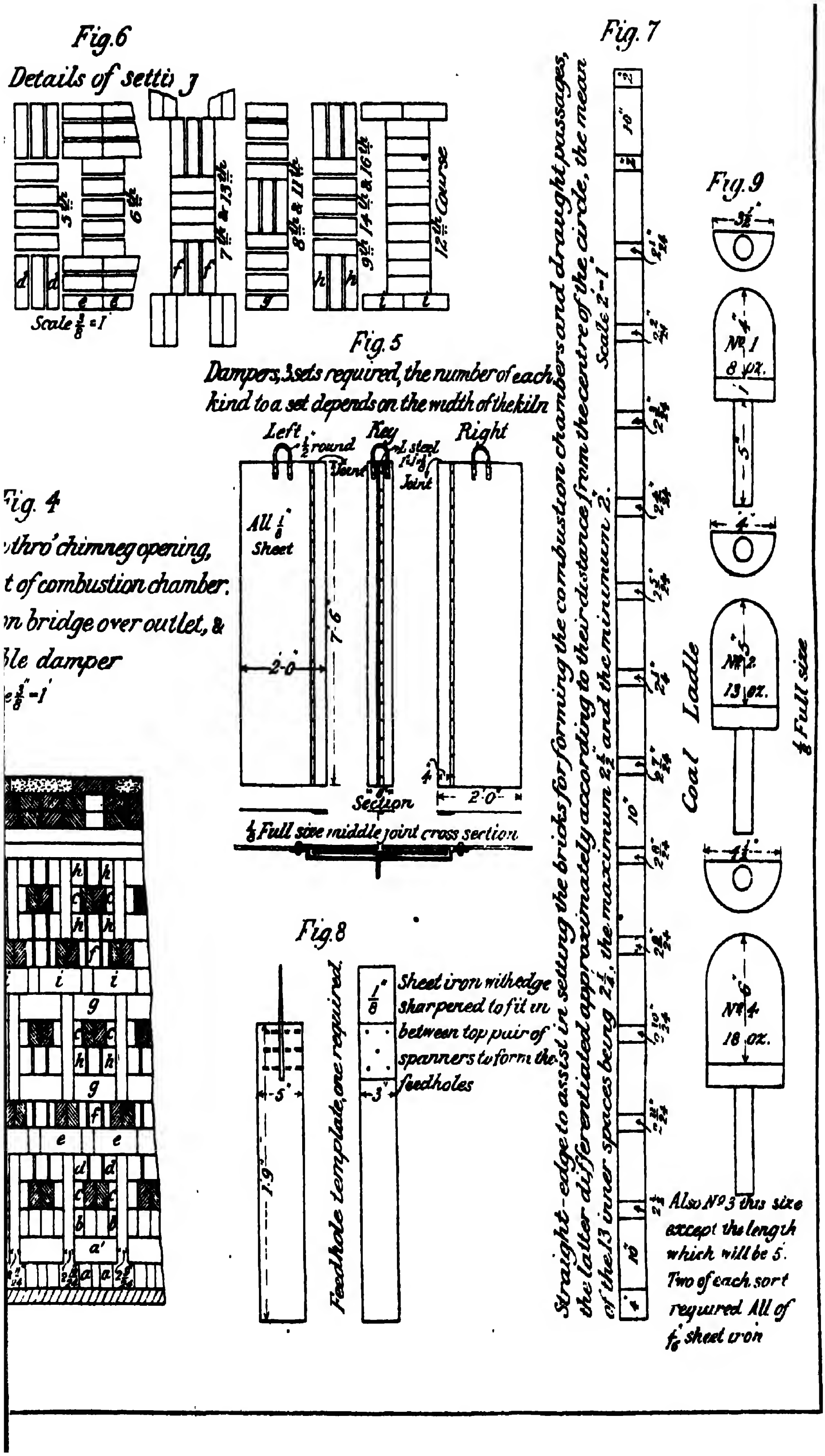


Fig. 6
Details of setting
5th
6th
7th & 13th
8th & 11th
9th, 14th & 16th
12th Course
Scale 3/8" = 1'
Fig. 5
Dampers, 3 sets required, the number of each kind to a set depends on the width of the kiln
Left
Key
Right
½ round
Joint
1 steel
Joint
All 1/8" Sheet
7'6"
2'0"
Section
2'0"
¼ Full size middle joint cross section
Fig. 4
thro' chimney opening,
t of combustion chamber.
n bridge over outlet, &
ble damper
Scale 3/8" = 1'
Fig. 8
Feedhole template, one required.
Sheet iron with edge sharpened to fit in between top pair of spanners to form the feedholes
1'9"
Fig. 7
Straight-edge to assist in setting the bricks for forming the combustion chambers and draught passages, the latter differentiated approximately according to their distance from the centre of the circle, the mean of the 13 inner spaces being 2¼, the maximum 2⅜ and the minimum 2.
Scale 2" = 1'
Fig. 9
Coal Ladle
¼ Full size
No 1
8 oz.
No 2
13 oz.
No 4
18 oz.
Also No 3 this size except the length which will be 5. Two of each sort required. All of 1/16" sheet iron

...KOTE PATTERN TILE KILN.

Scale 4 Feet = 1 Inch

SECTION ON A.B.

Scale 3/8" = 1'

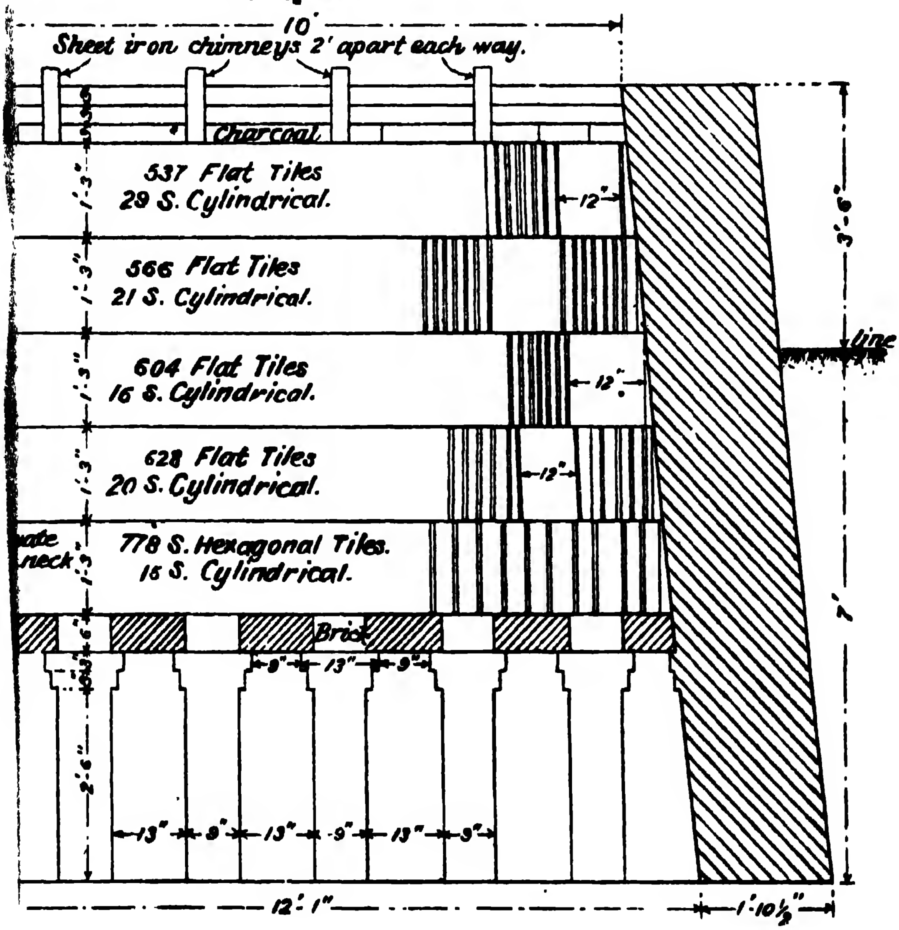
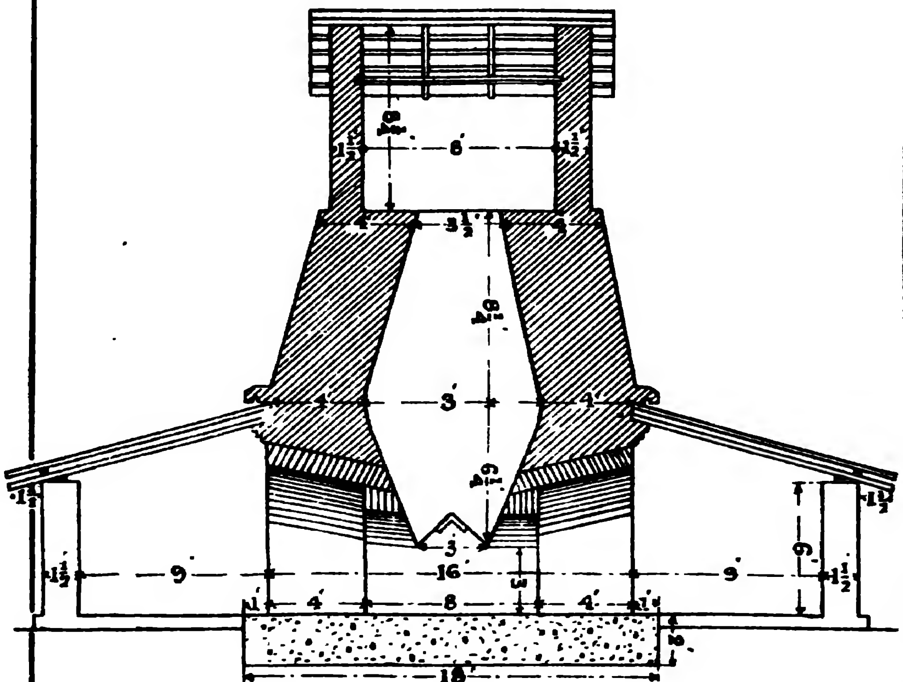


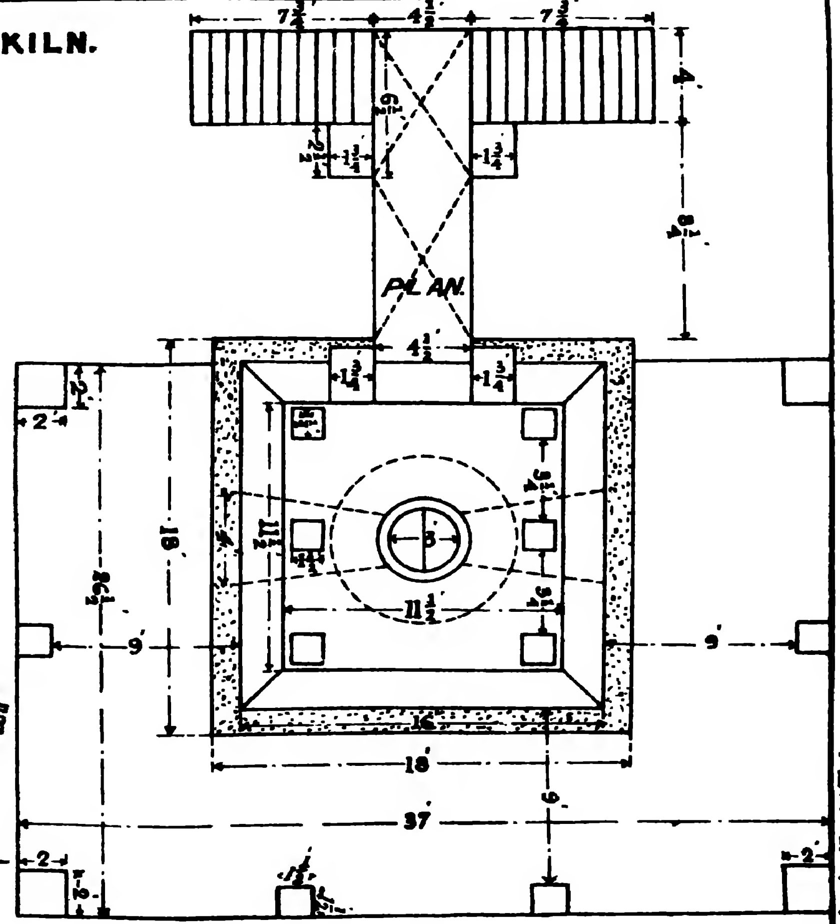
PLATE. III.

LIME KILN.

This may be built singly or several can be built together in a block, according to requirements, each kiln will burn about 150 cubic feet per day.

SECTION.





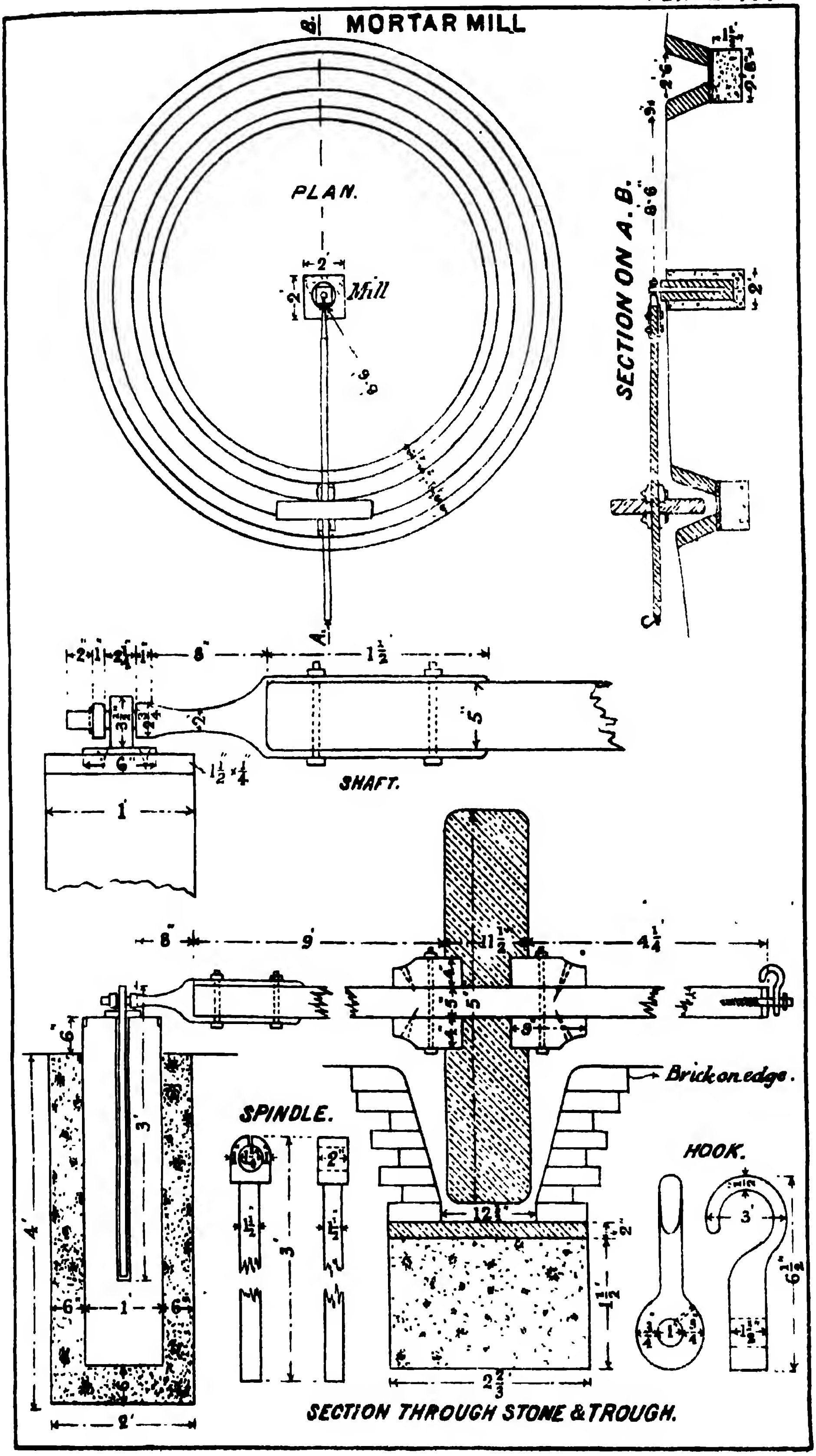

MORTAR MILL
PLAN.
Mill
SECTION ON A. B.
SHAFT.
Brick on edge.
SPINDLE.
HOOK.
SECTION THROUGH STONE & TROUGH.

PLATE V.

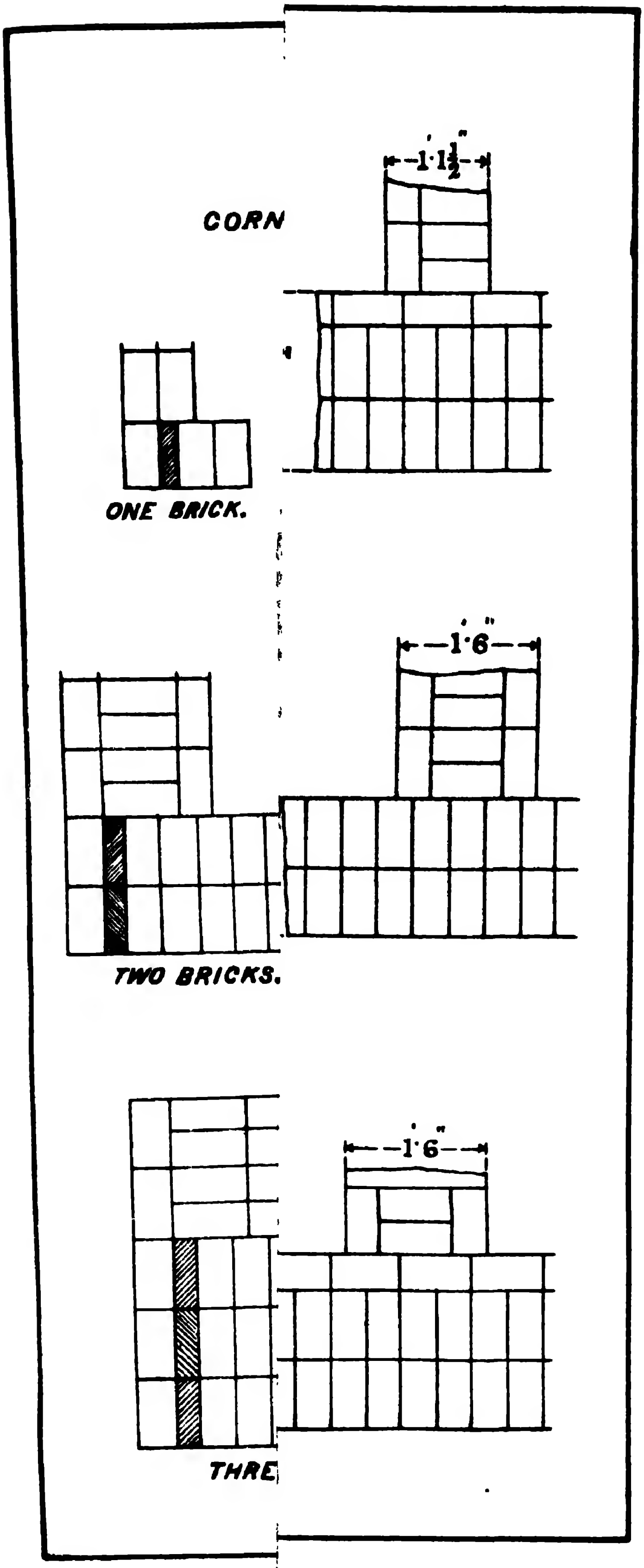
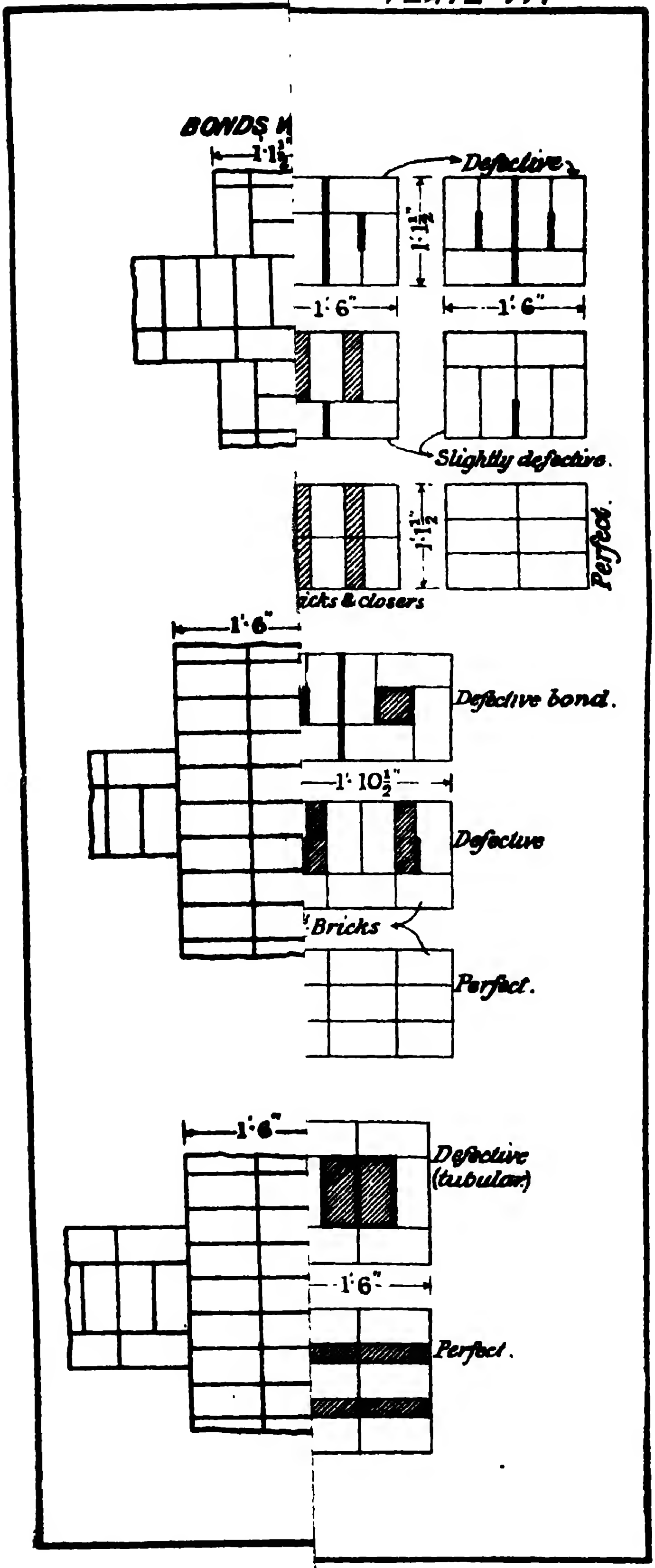
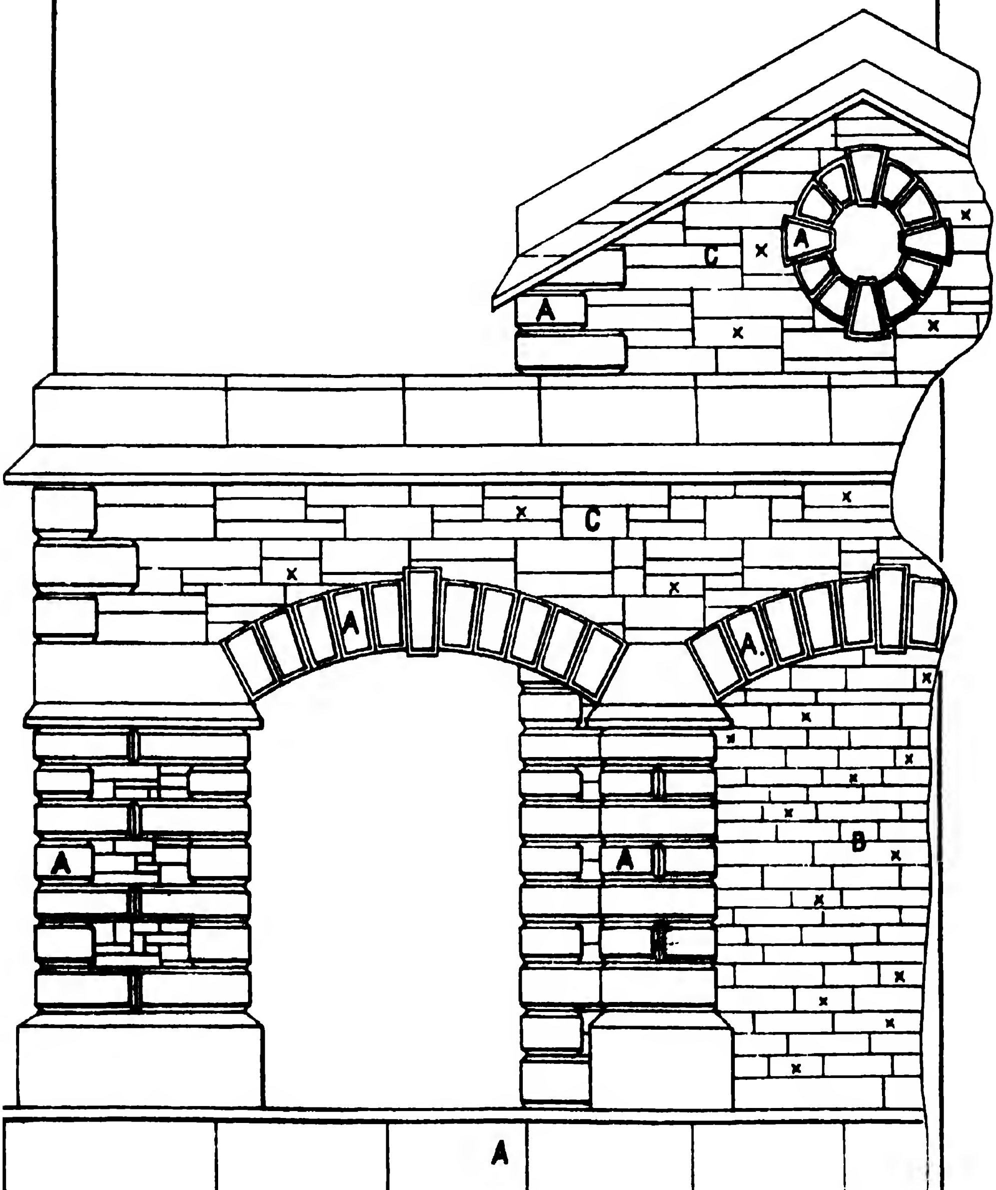


PLATE VI.


BONDS I
1' 1½"
Defective
1' 1½"
1' 6"
1' 6"
Slightly defective.
1' 1½"
Perfect.
icks & closers
1' 6"
Defective bond.
1' 10½"
Defective
Bricks
Perfect.
1' 6"
Defective
(tubular)
1' 6"
Perfect.

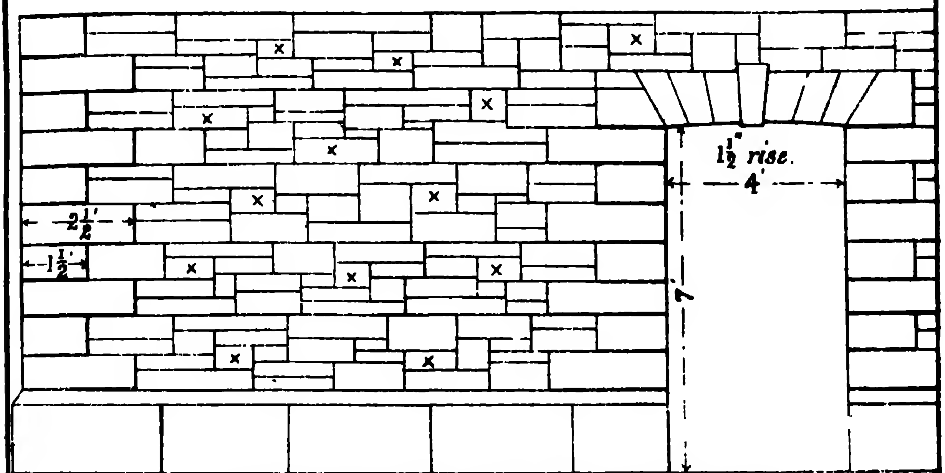
STONE MASONRY. SUITABLE POSITIONS.



A - *Ashlar.*
B - *Coursed rubble with ashlar quoins.*
C - *Random squared rubble.*
Through-bonds marked ×

RANDOM RUBBLE.

FIG. 1.



Random squared rubble with ashlar quoins.

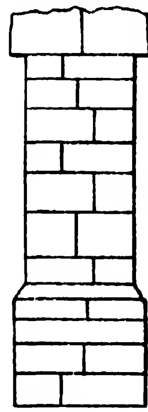
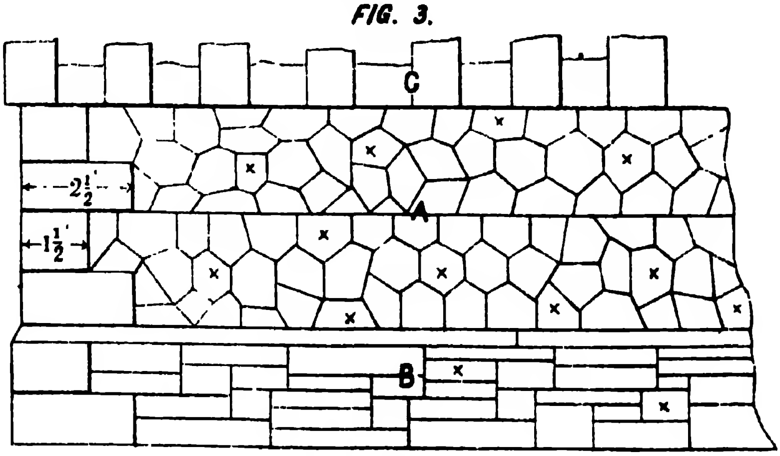


FIG. 2.
SECTION OF WALL.

FIG. 3.



A - *Random rubble.*
B - *Random squared rubble.*
C - *Scotch coping*
Through-bonds marked thus ×

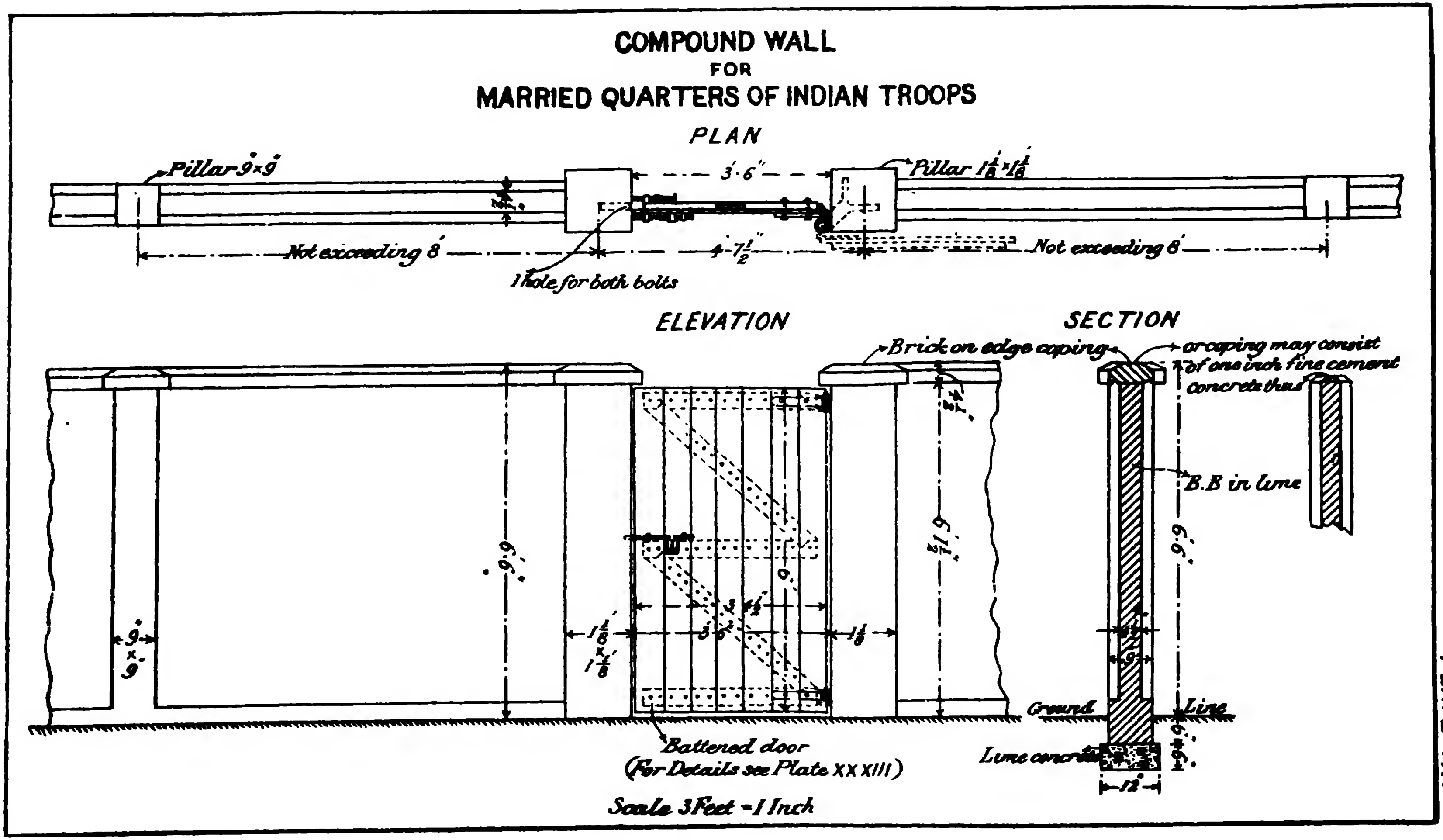
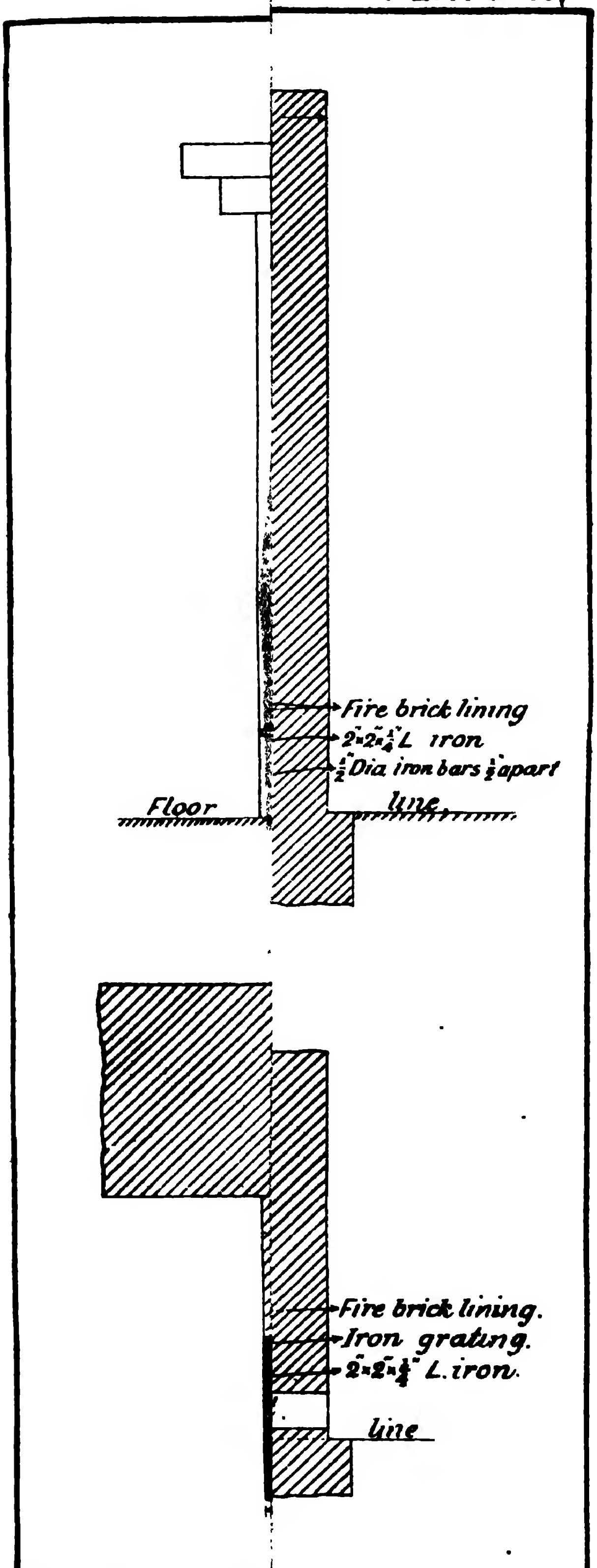

COMPOUND WALL
FOR
MARRIED QUARTERS OF INDIAN TROOPS
PLAN
Pillar 9"×9"
Pillar 1'1/8×1'1/8
3'·6"
Not exceeding 8'
4'·7½"
Not exceeding 8'
1 hole for both bolts
ELEVATION
SECTION
Brick on edge coping
or coping may consist of one inch fine cement concrete thus
B.B in lime
6'·6"
6'·1½"
4½"
9"×9"
1'1/8×1'1/8
1'1/8
3'·6"
3'·4½"
6'
Ground
Line
Lime concrete
12"
Battened door
(For Details see Plate XXXIII)
Scale 3 Feet = 1 Inch

PLATE X.



The following co

The bars are to be

plate X. The grating is

CHIMNEY STACKS.

Scale 2' = 1 inch.

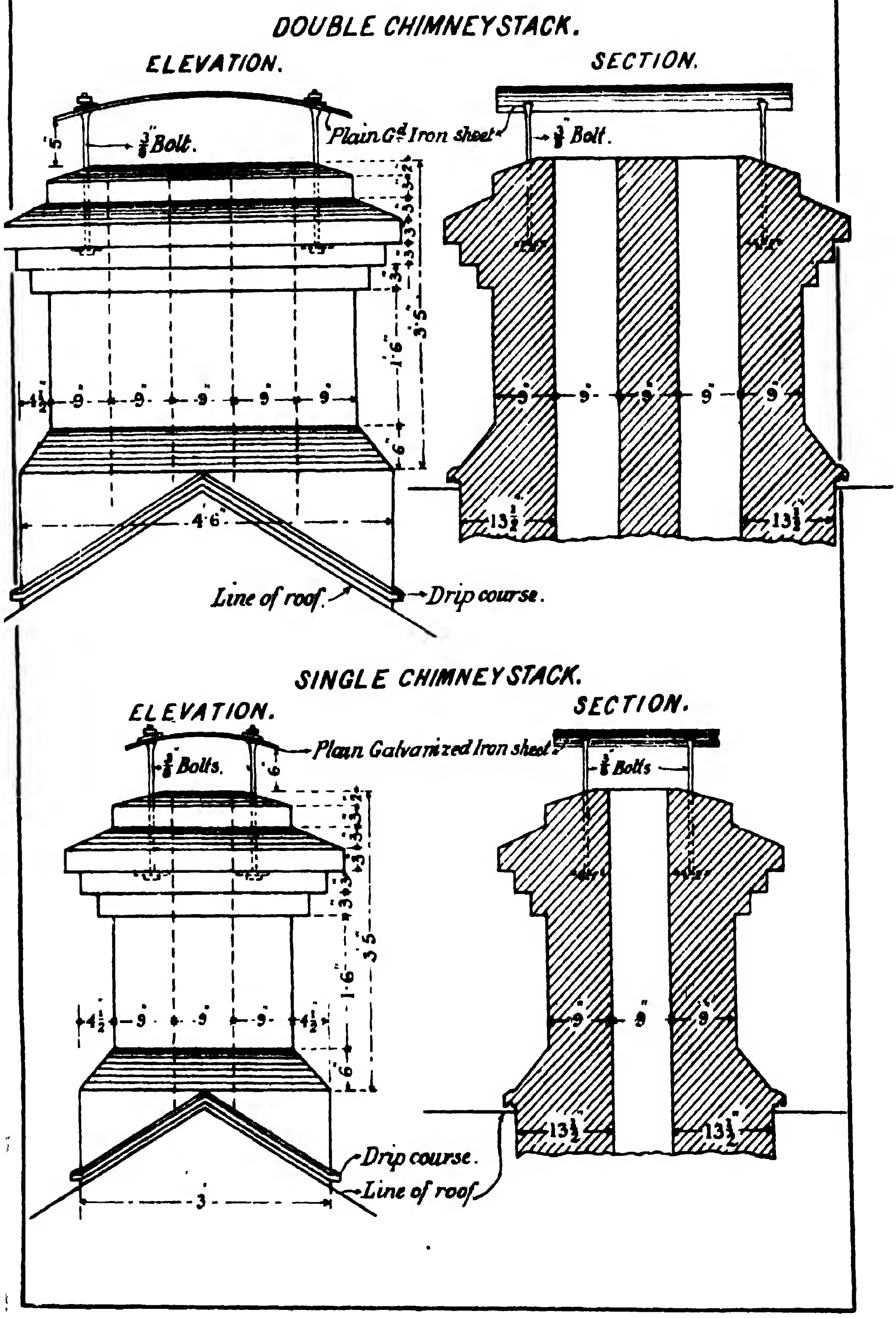


PLATE XII

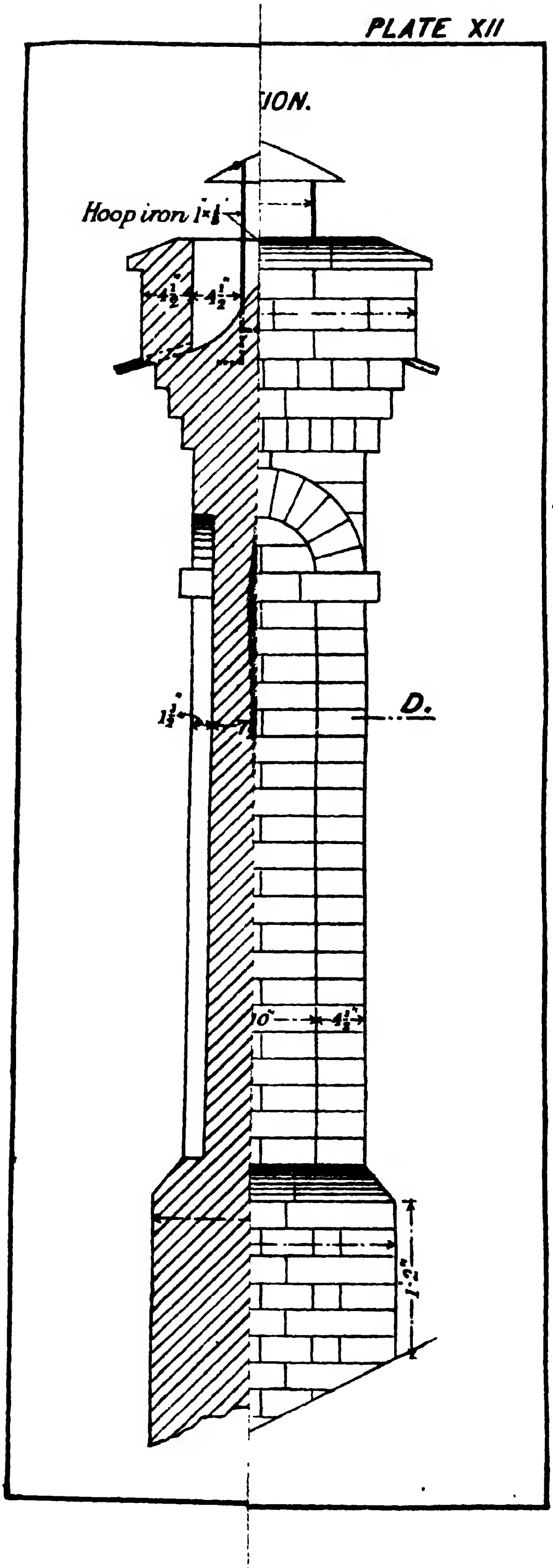
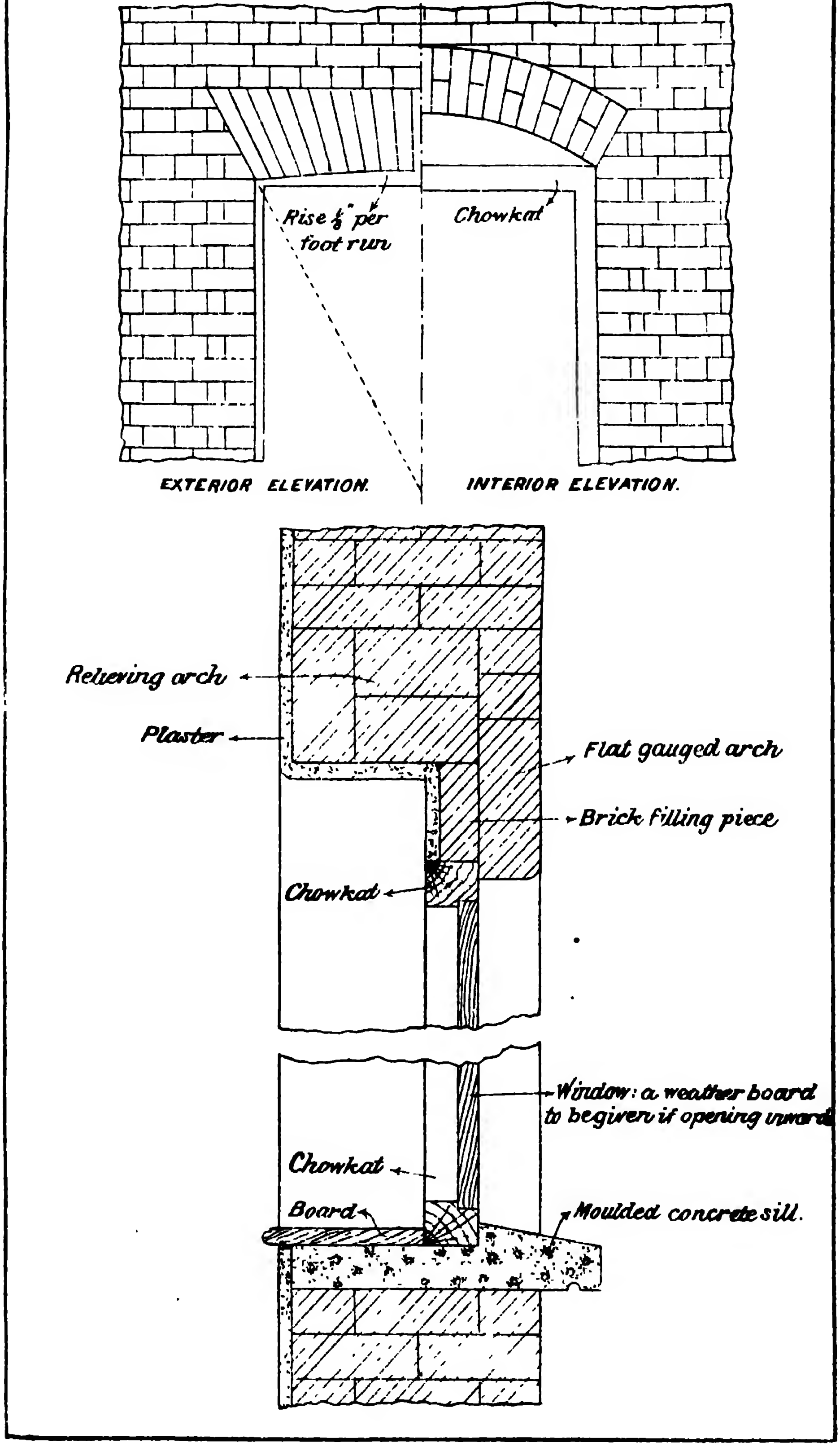
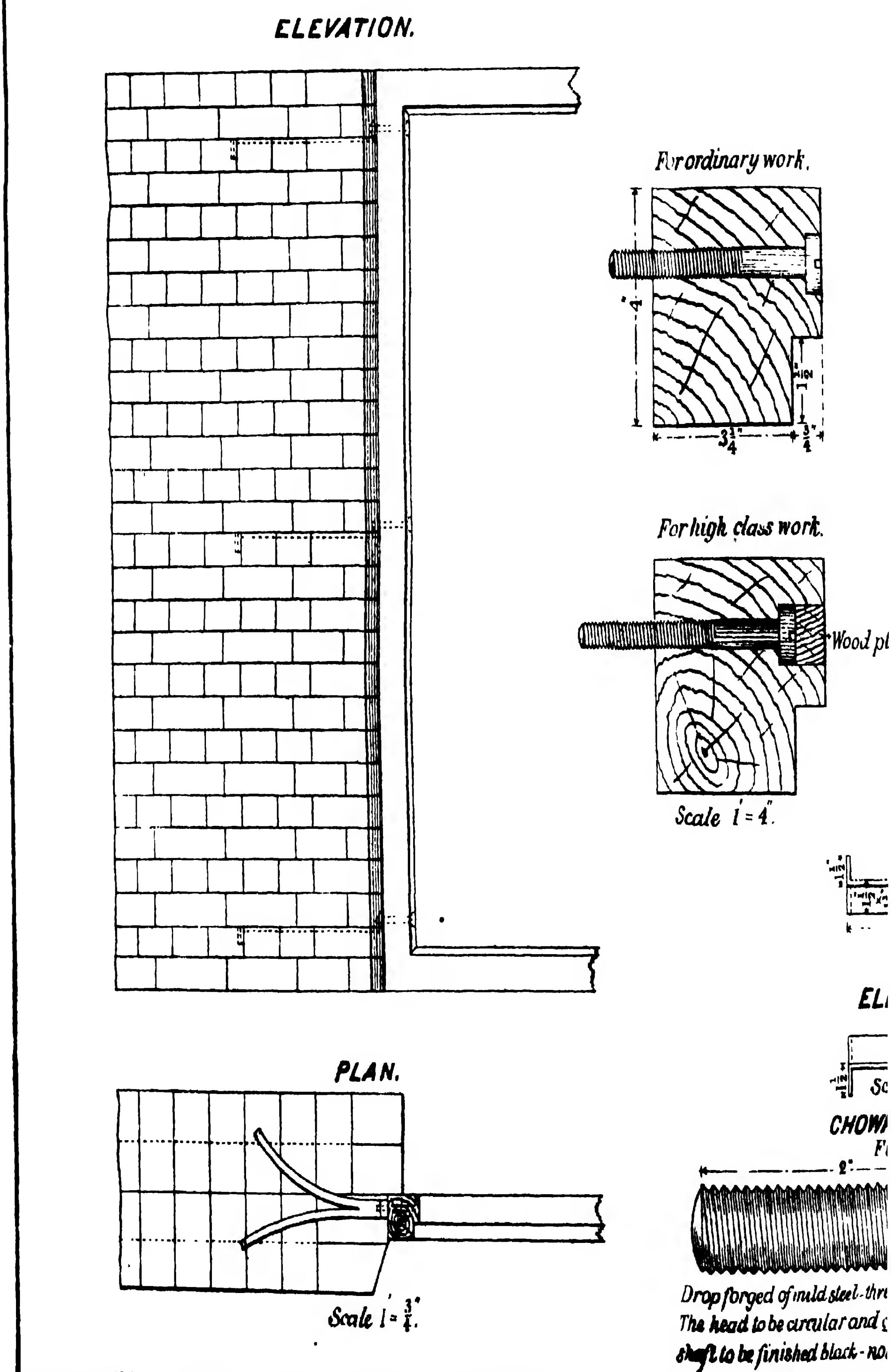


PLATE XIII.

FLAT AND RELIEVING ARCHES.



HOLDFASTS FOR CHOWKATS.



METHODS OF ADDING VERANDAH TO BRICK WALL

Fig 1

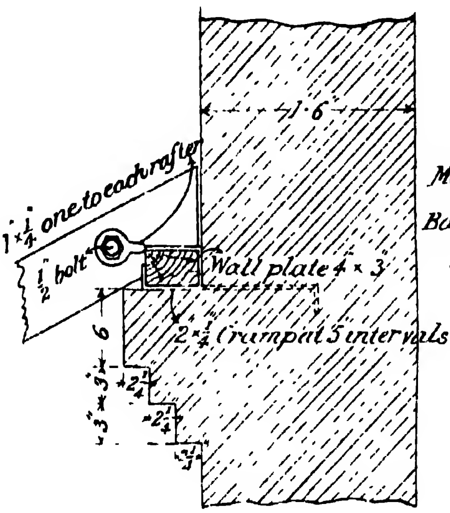


Fig. 2

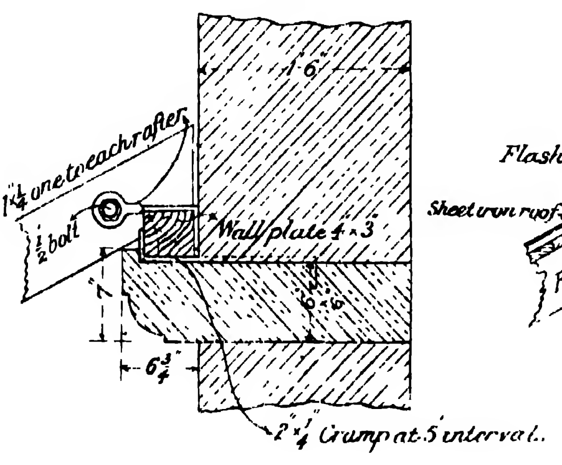


Fig. 3

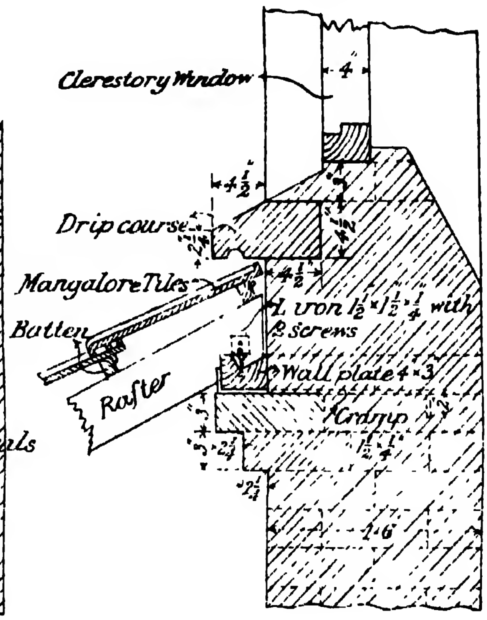
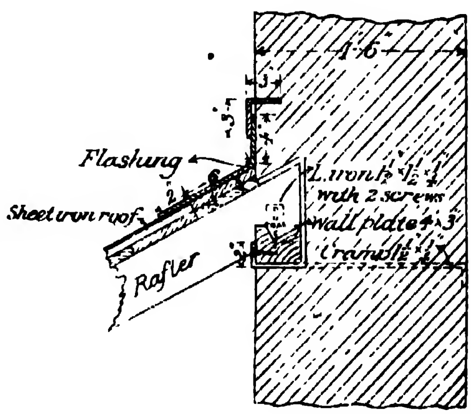
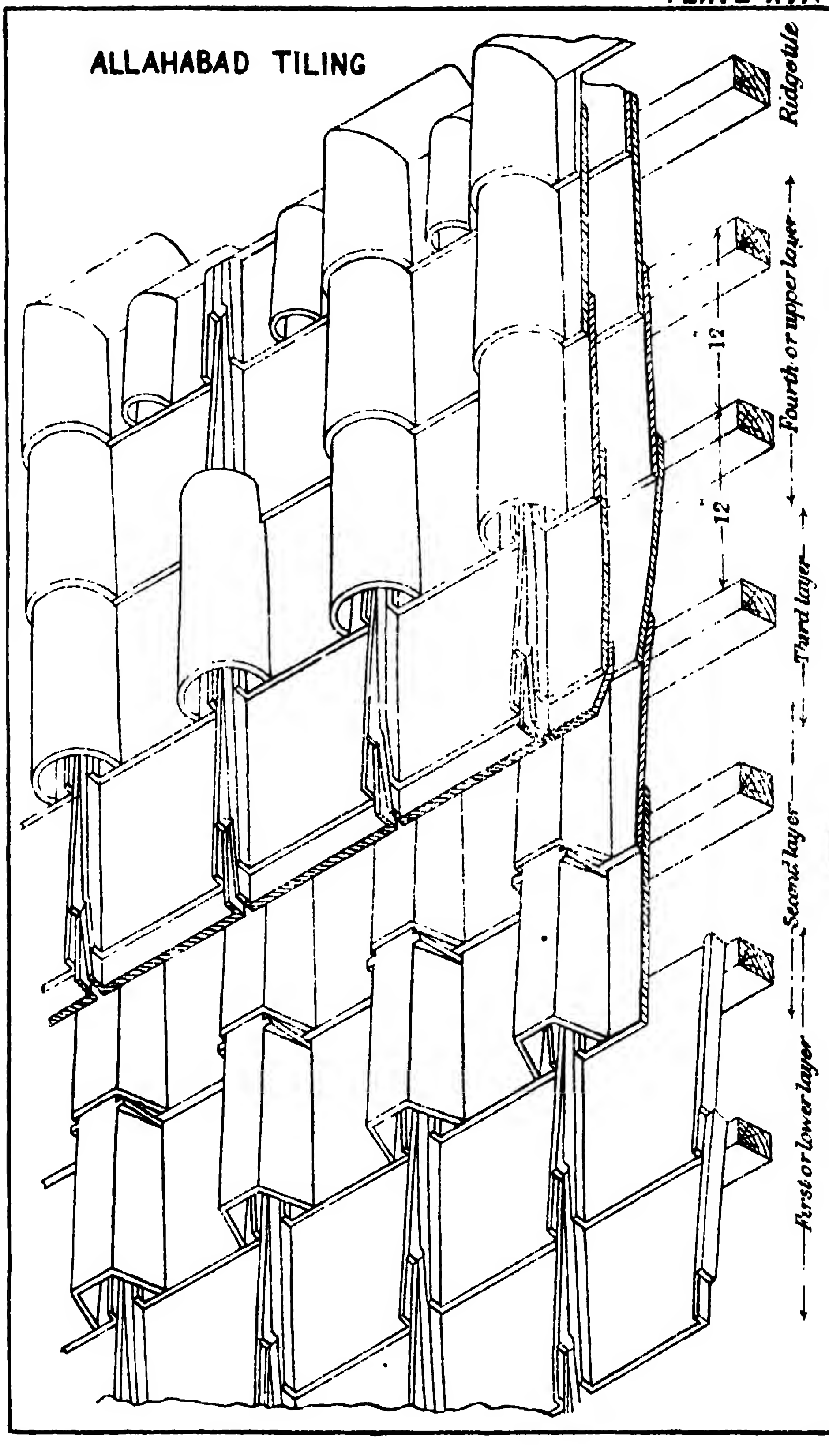
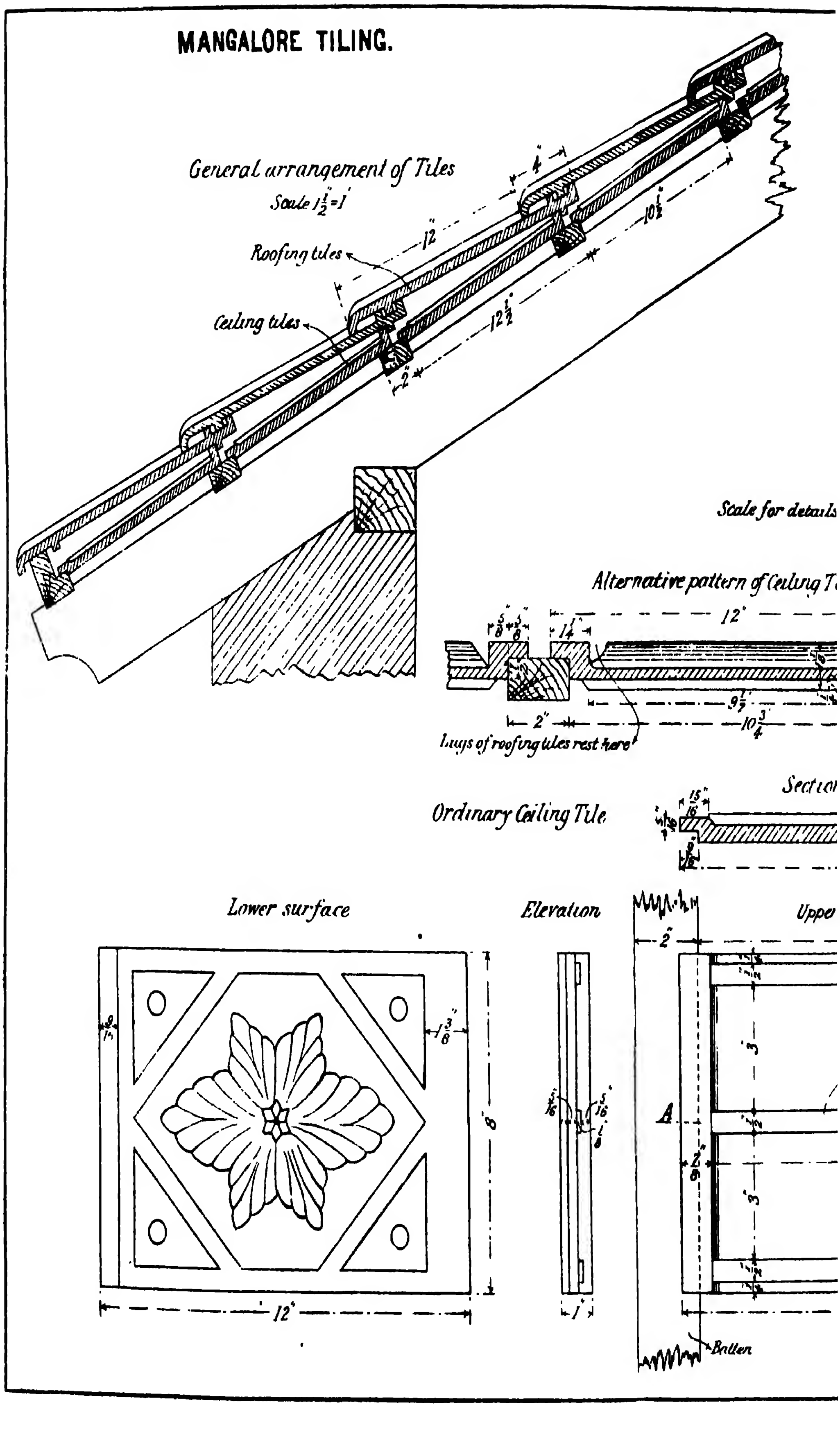


Fig 4




ALLAHABAD TILING
Ridge tile
Fourth or upper layer
12
12
Third layer
Second layer
First or lower layer

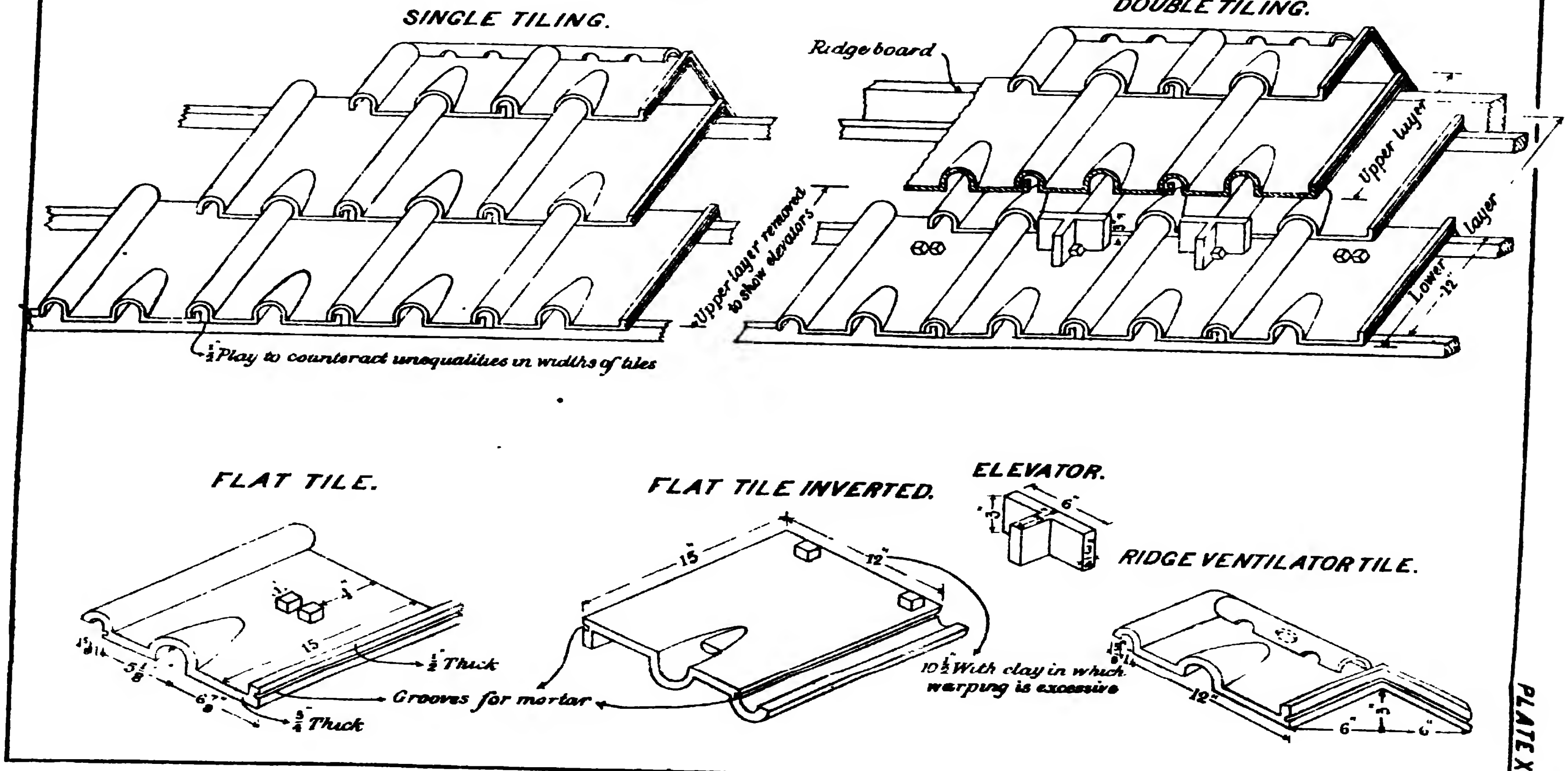


MANGALORE TILING.
General arrangement of Tiles
Scale 1½" = 1'
Roofing tiles
Ceiling tiles
Scale for details
Alternative pattern of Ceiling T
Lugs of roofing tiles rest here
Section
Ordinary Ceiling Tile
Lower surface
Elevation
Upper
A
Batten

PLATE XVIII.

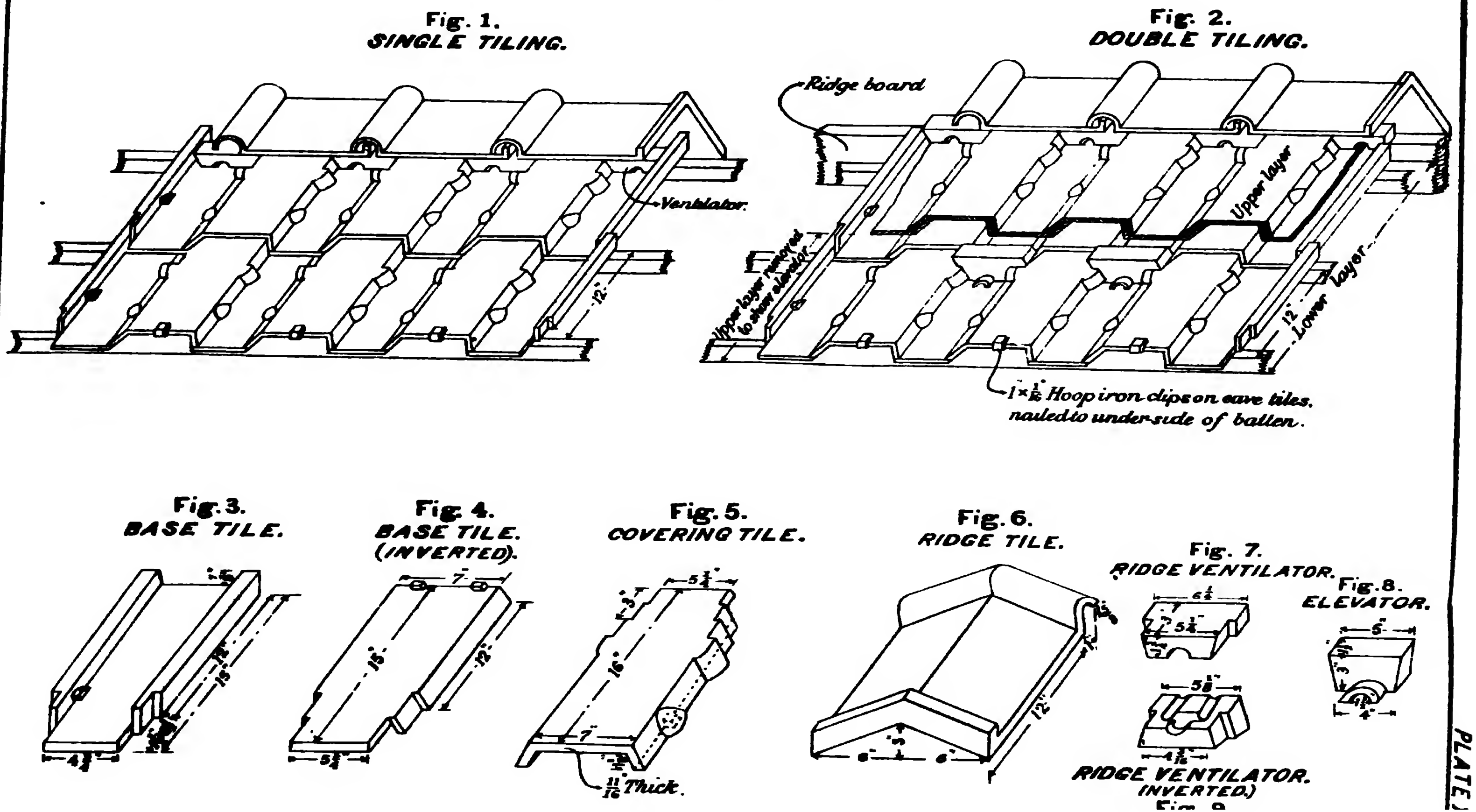
SIALKOT PATTERN ROOF TILING.

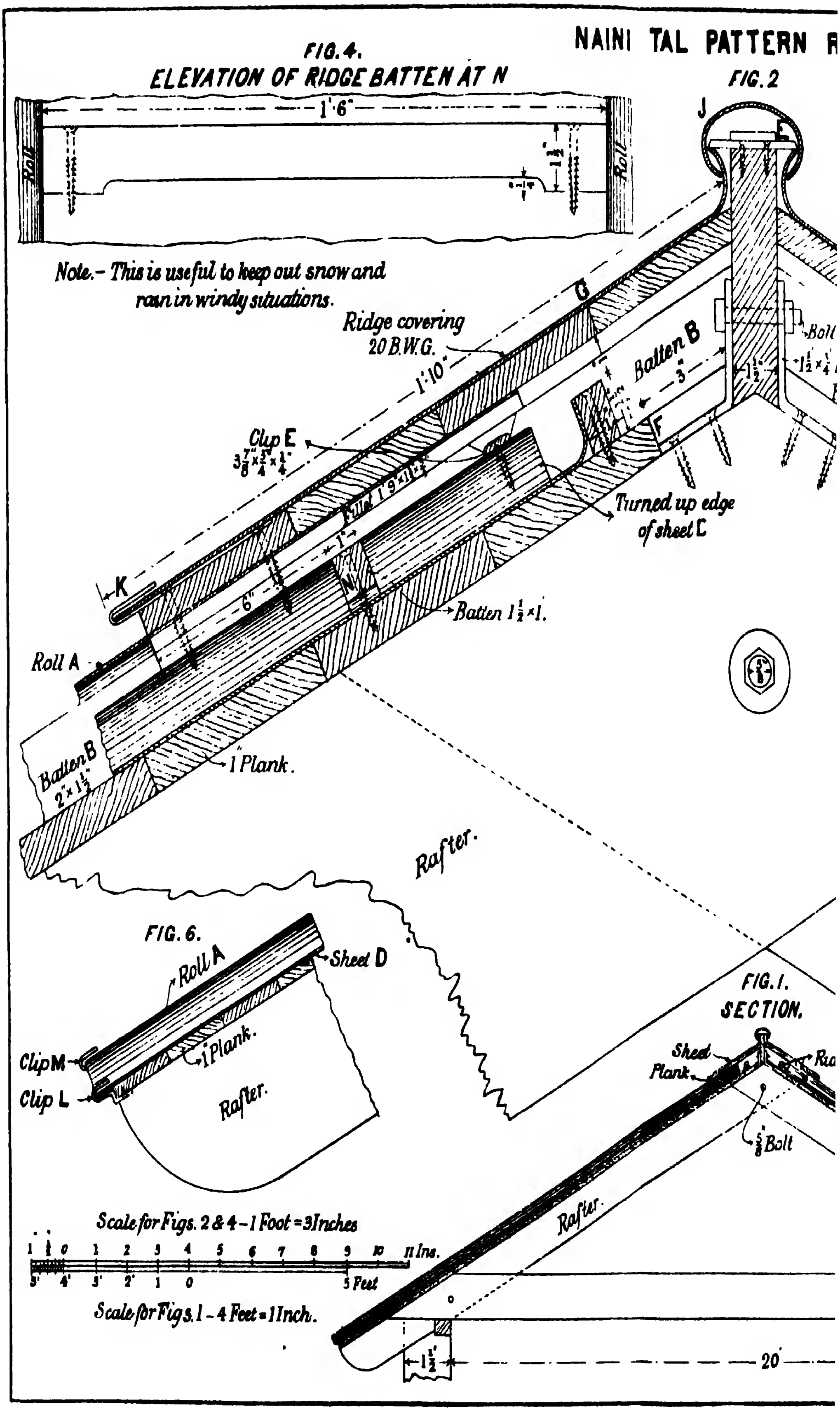
Scale for general views, 1" = ¾".
Scale for details, 1 = 1".



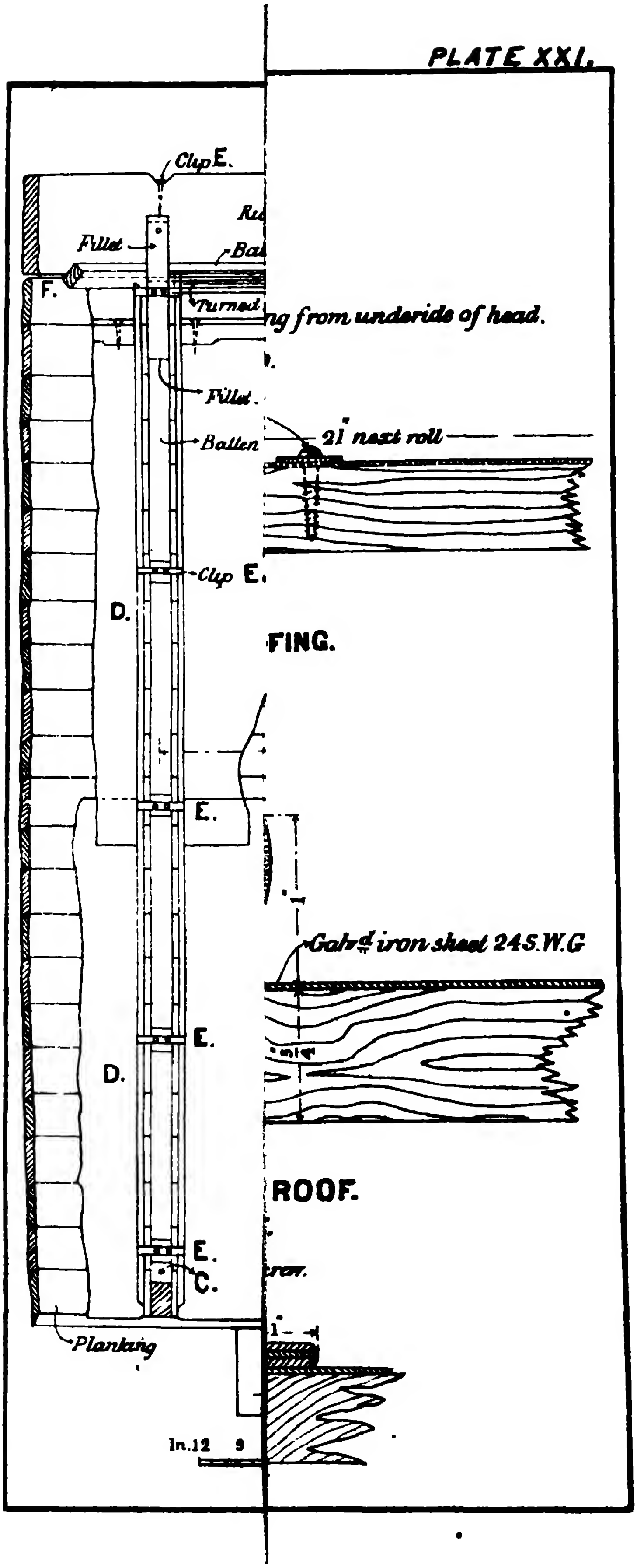
SMITH'S PAN TILING.

Scale for Figs. 1 & 2, 1' = 3/4".
Scale for Figs. 3 to 9, 1' = 1".





NAINI TAL PATTERN R
FIG. 4.
ELEVATION OF RIDGE BATTEN AT N
1'·6"
Roll
Roll
Note.- This is useful to keep out snow and rain in windy situations.
FIG. 2
J
Ridge covering 20 B.W.G.
G
1'·10"
Batten B
3"
Bolt
F
Clip E
Turned up edge of sheet C
K
6"
1"
N
Batten 1½×1.
Roll A
Batten B 2"×1½"
1" Plank.
Rafter.
FIG. 6.
Roll A
Sheet D
Clip M
Clip L
1 Plank.
Rafter.
FIG. 1.
SECTION.
Sheet
Plank
⅝ Bolt
Rafter.
Scale for Figs. 2 & 4 - 1 Foot = 3 Inches
11 Ins.
5 Feet
Scale for Figs. 1 - 4 Feet = 1 Inch.
1½"
20'


Clip E.
Fillet
Turned
ng from underside of head.
Fillet.
Batten
21" next roll
Clip E.
D.
FING.
E.
Galvd iron sheet 24 S.W.G
E.
D.
ROOF.
E.
C.
F.
Planking
In.12 9